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Tel. No.: 202-371-2600
For: Apparatus and Method for Rectangular-to-Polar Conversion





FIG. 1A
A SIMPLIFIED PSK TRANSMITTER

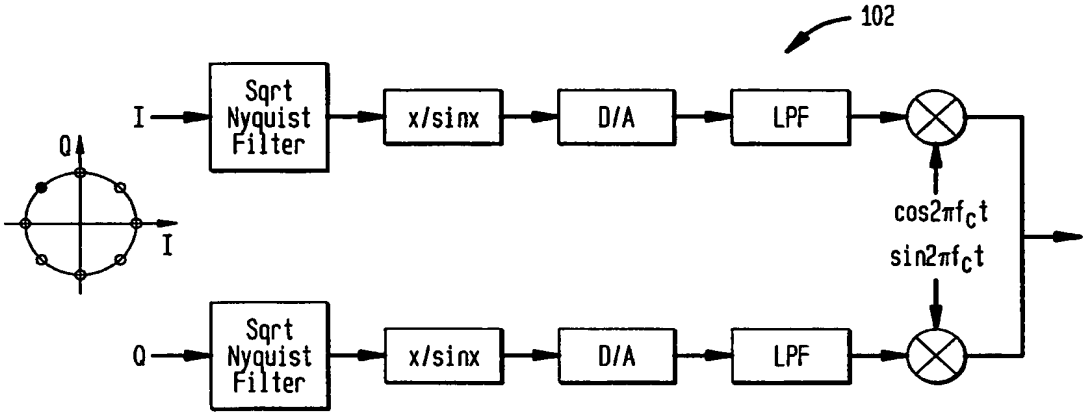
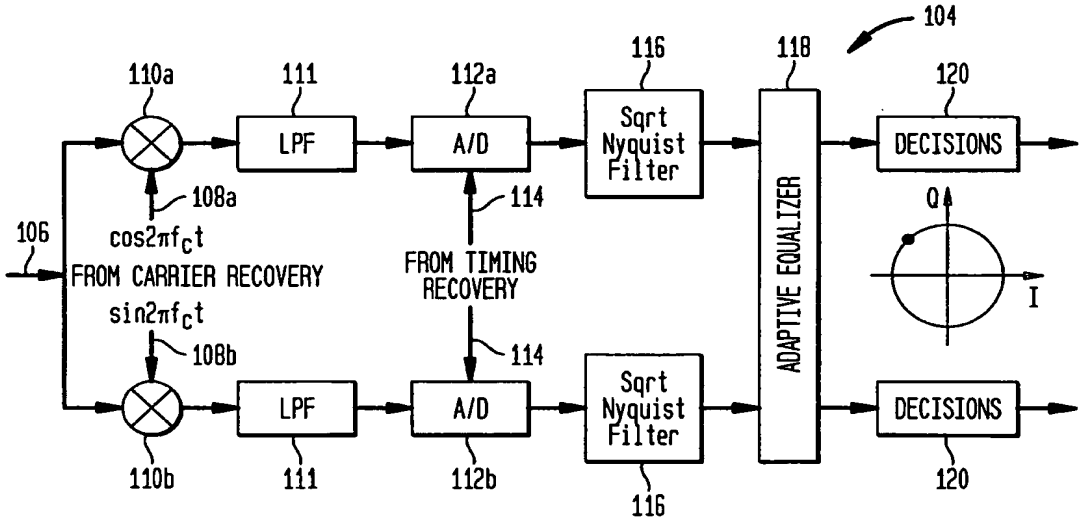



FIG. 1B
A SIMPLIFIED PSK RECEIVER



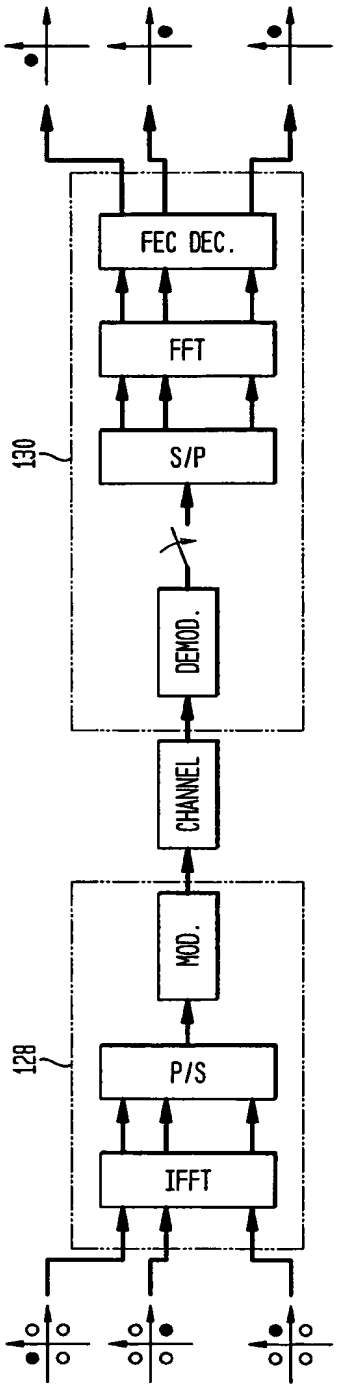



FIG. 1C
SIMPLIFIED BLOCK DIAGRAM OF AN OFDM SYSTEM

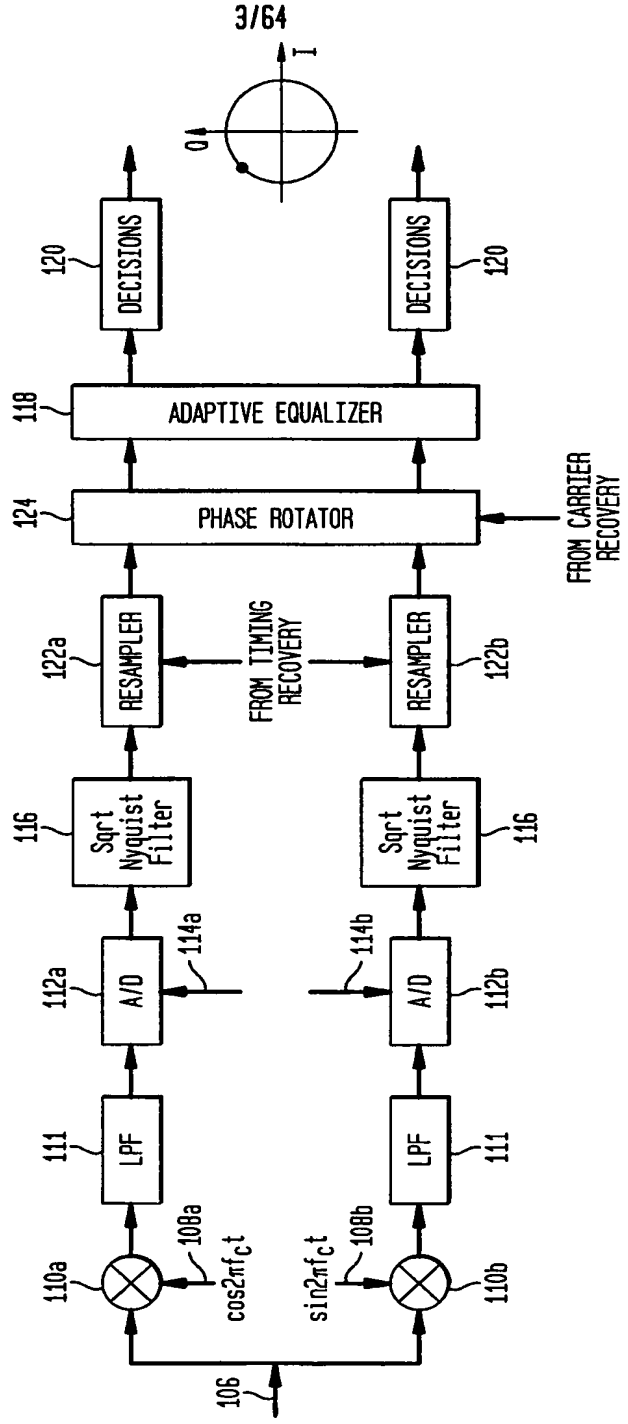



FIG. 1D
PSK RECEIVER WITH CARRIER AND TIMING RECOVERY

*FIG. 2*
INTERPOLATION ENVIRONMENT

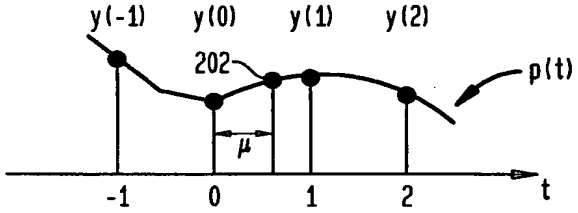
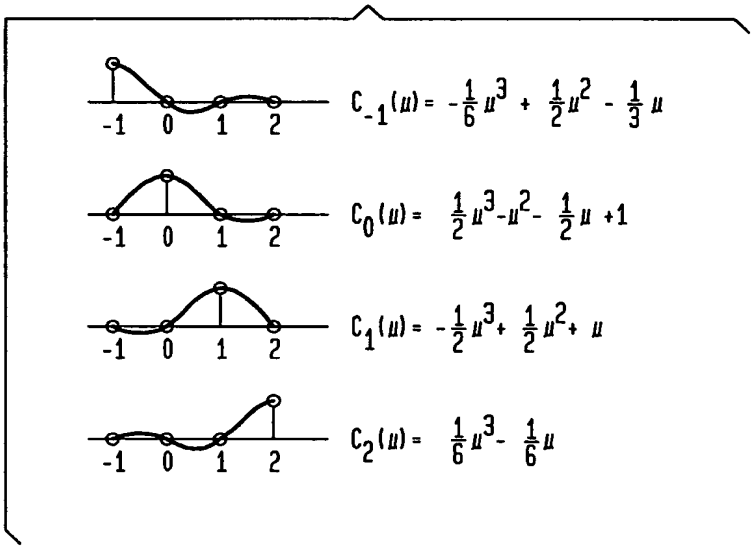



*FIG. 3*
THE LAGRANGE BASIS POLYNOMIALS



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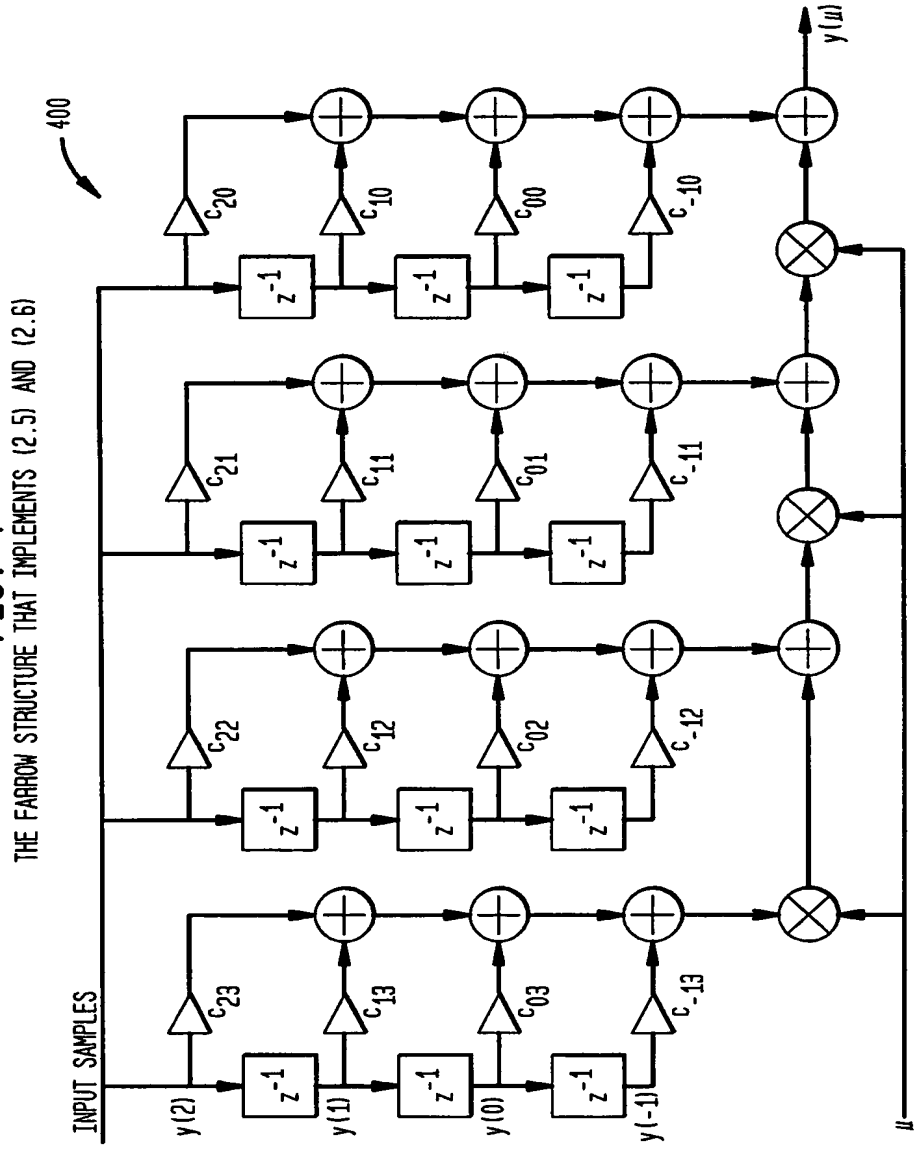


FIG. 4
THE FARROW STRUCTURE THAT IMPLEMENTS (2.5) AND (2.6)

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FIG. 5

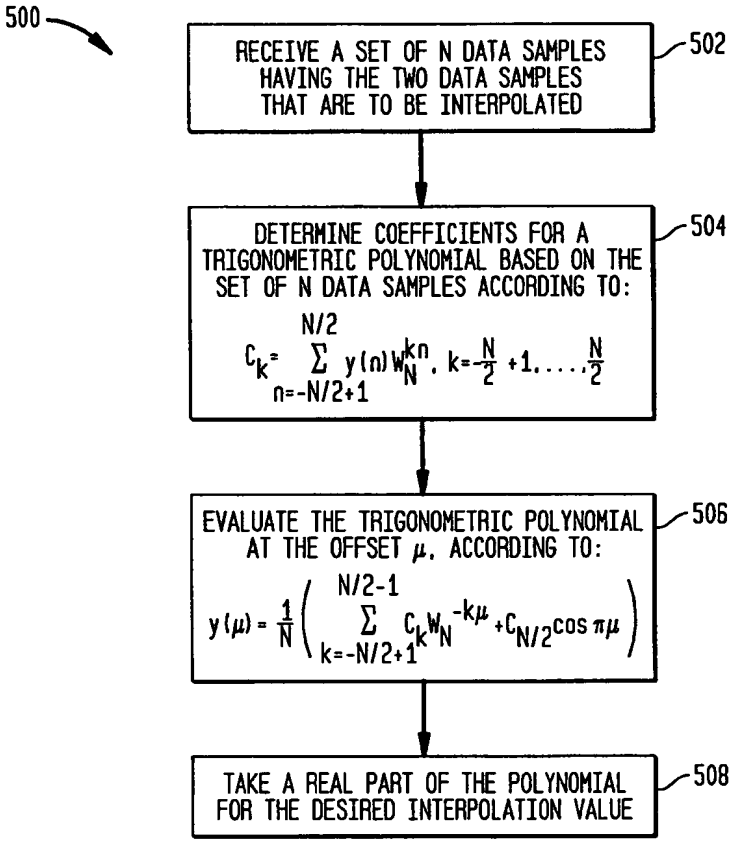


FIG. 6A
IMPULSE RESPONSES OF LAGRANGE INTERPOLATOR

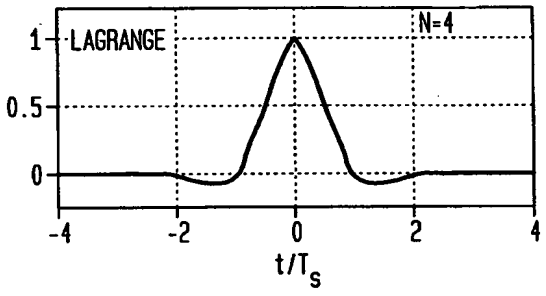



FIG. 6B
IMPULSE RESPONSES OF TRIGONOMETRIC INTERPOLATOR

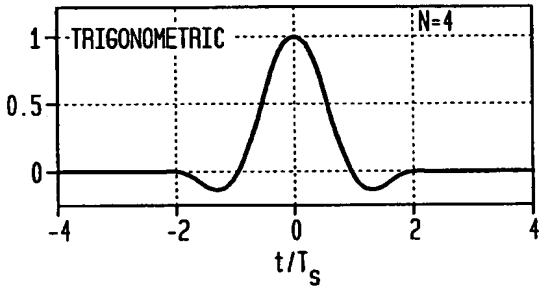



FIG. 7A
FREQUENCY RESPONSES FOR N=4

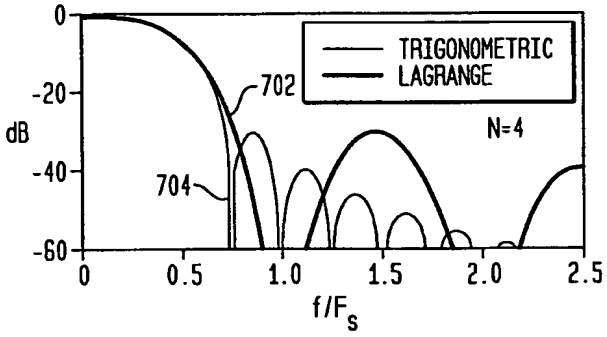


FIG. 7B

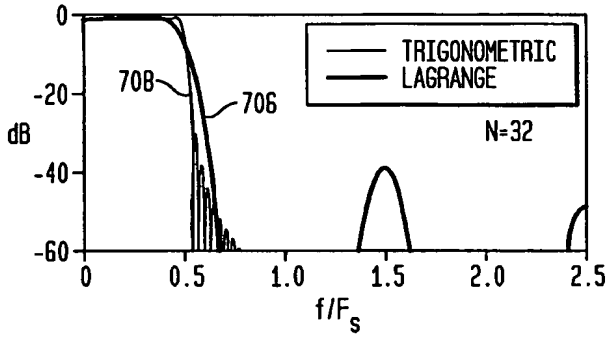



FIG. 8A

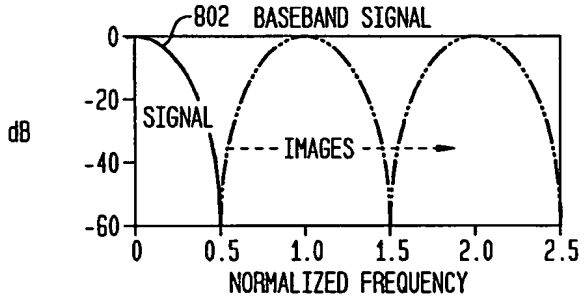
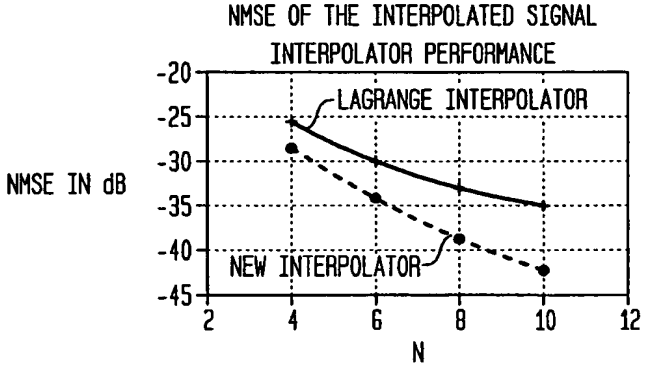



FIG. 8B



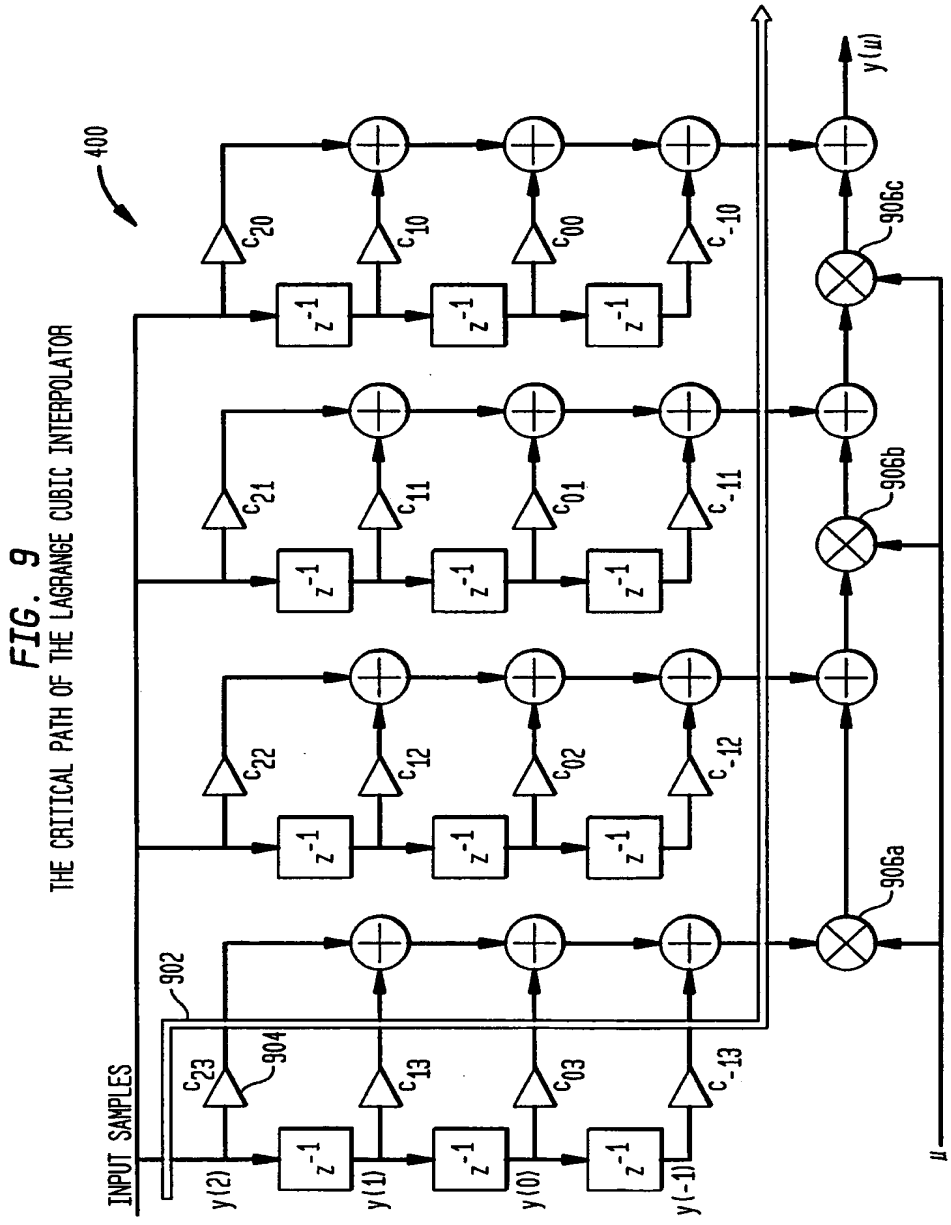



FIG. 9
THE CRITICAL PATH OF THE LAGRANGE CUBIC INTERPOLATOR

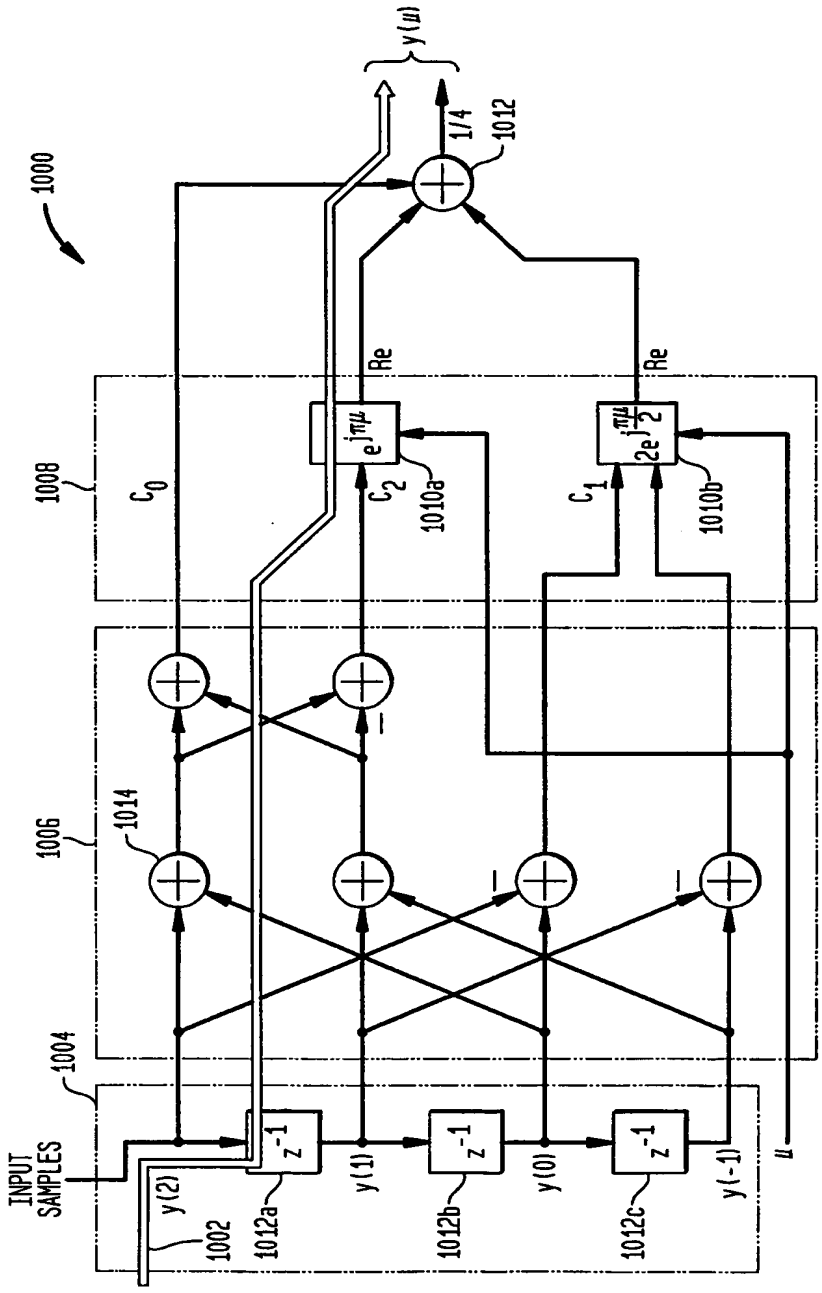



FIG. 10
TRIGONOMETRIC INTERPOLATOR (N=4)

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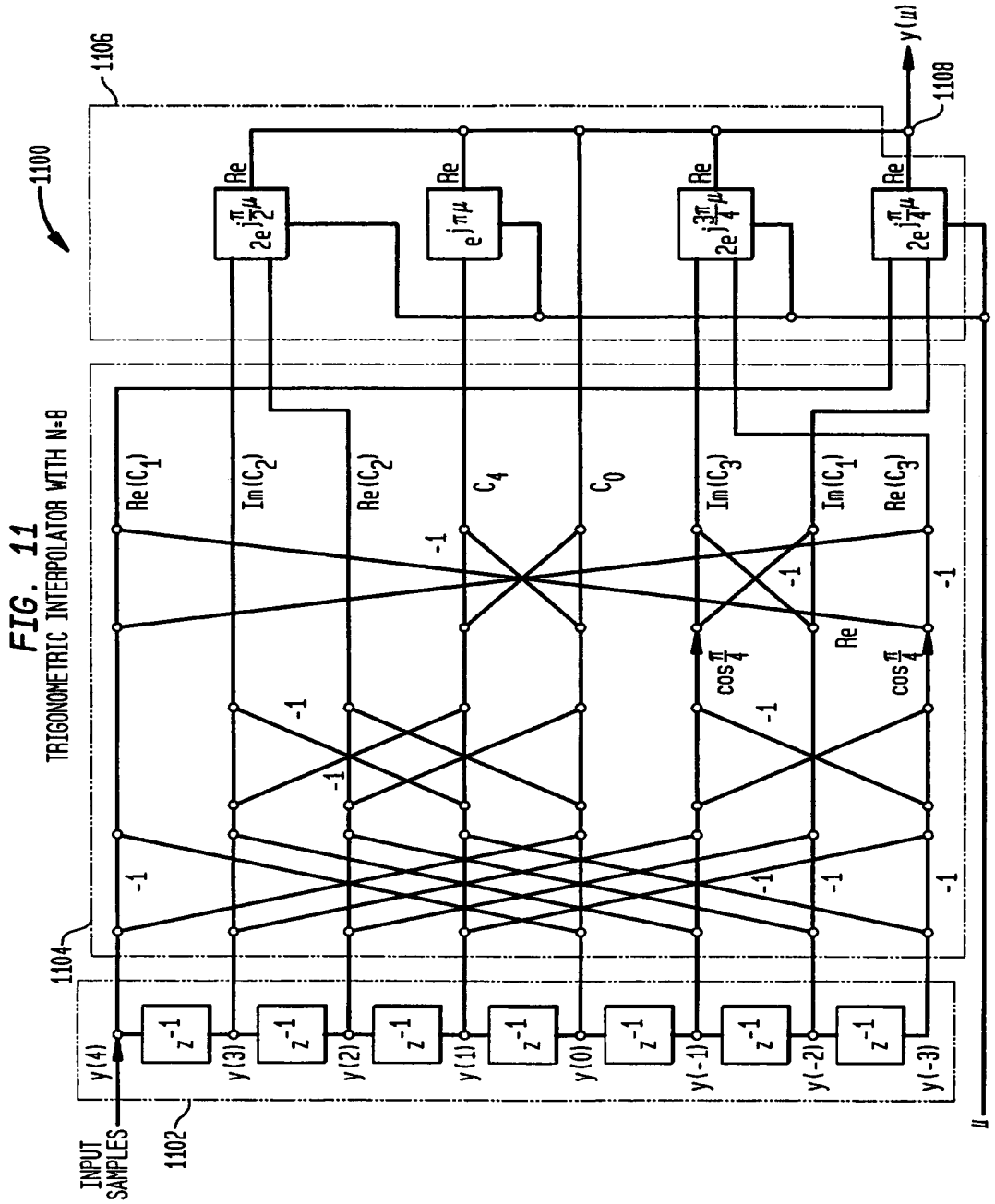



FIG. 11

*FIG. 12*
CONCEPTUAL MODIFICATION OF INPUT SAMPLES

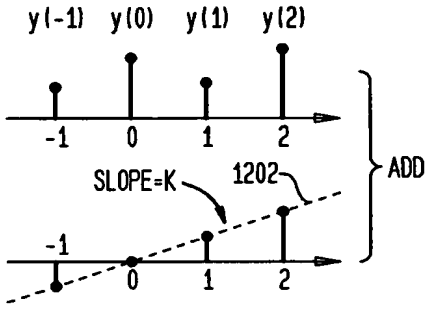
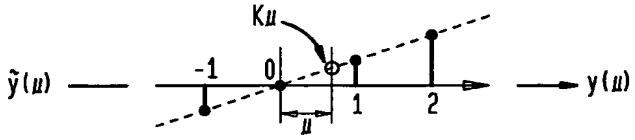



*FIG. 13*
CORRECTING THE OFFSET DUE TO MODIFICATION OF ORIGINAL SAMPLES



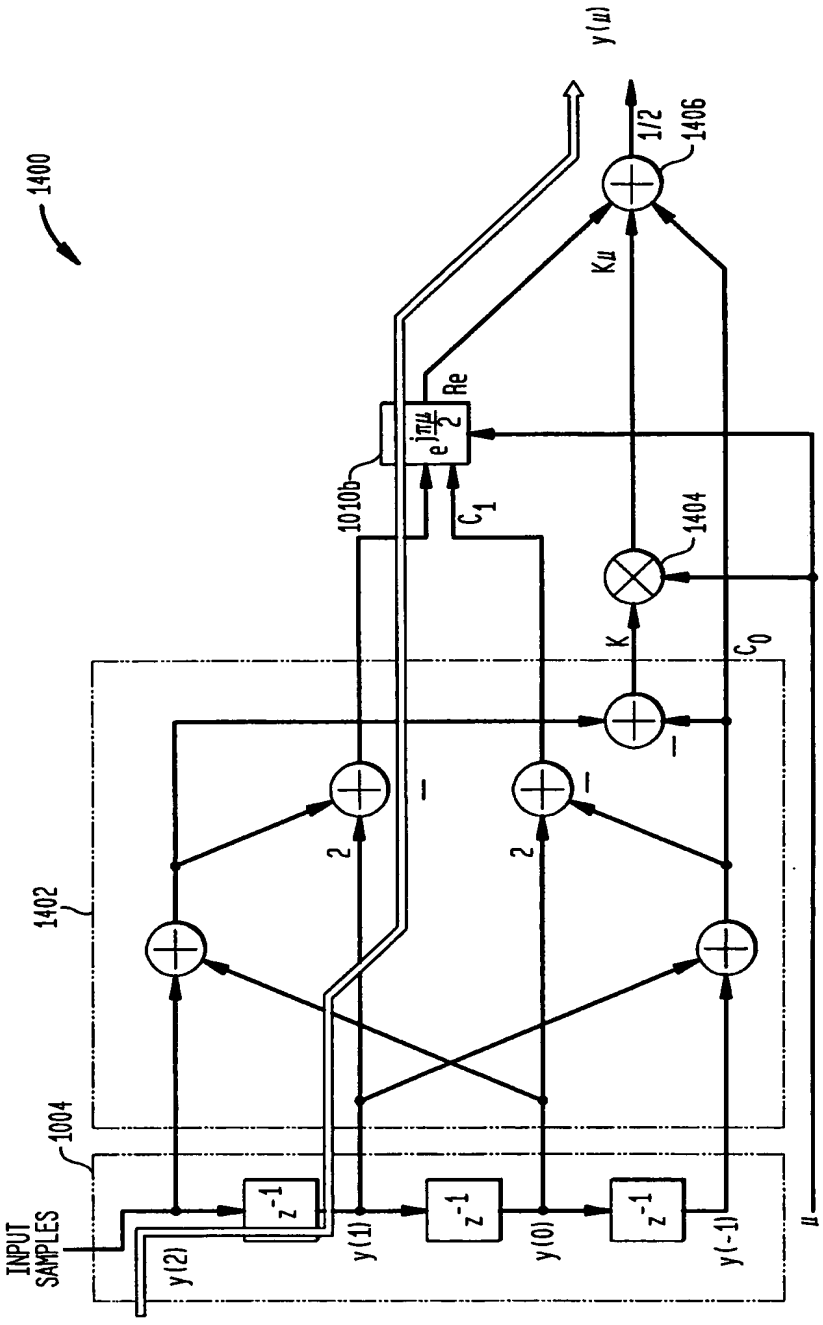



FIG. 14
TRIGONOMETRIC INTERPOLATOR N=4

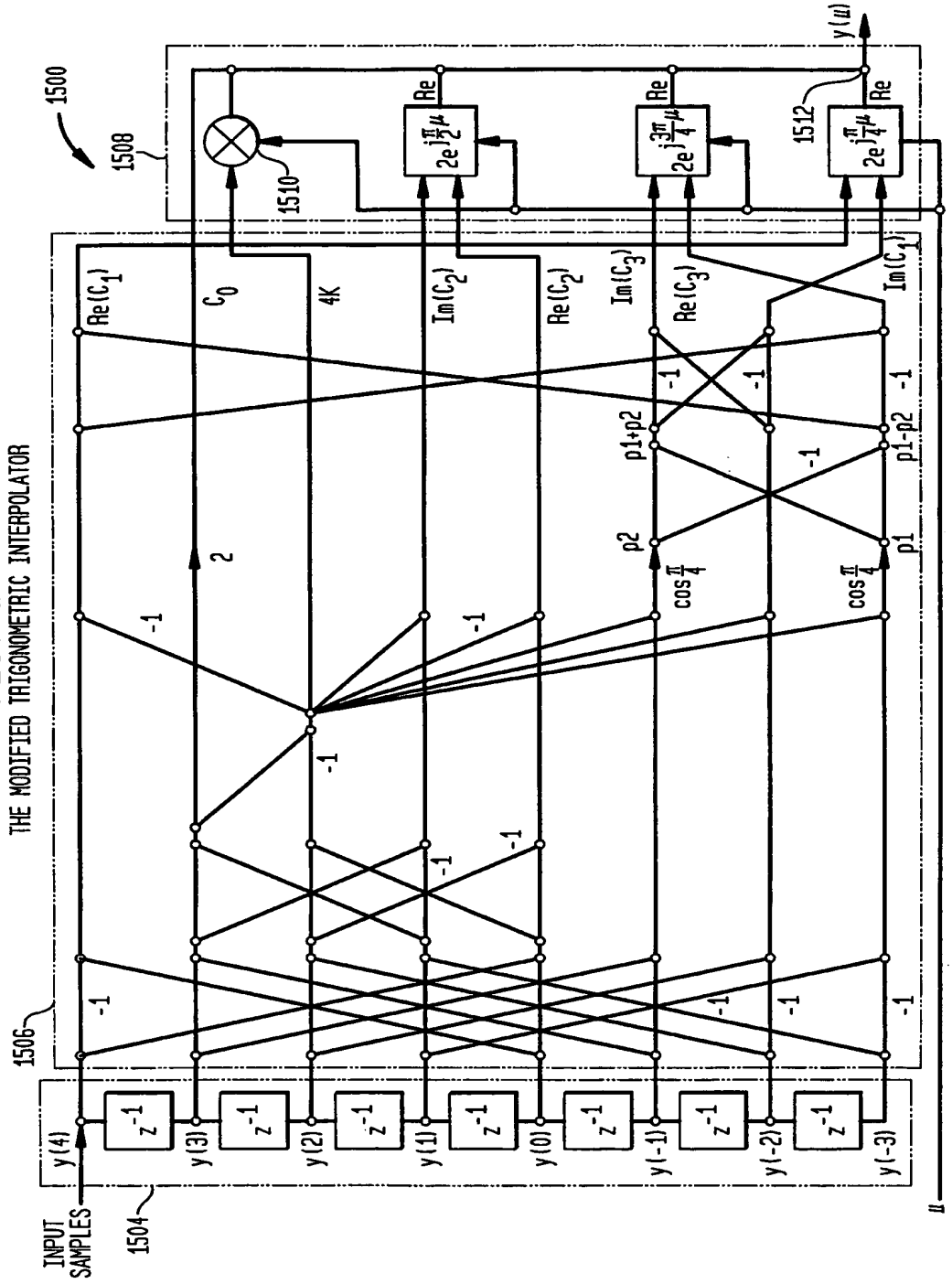



FIG. 15
THE MODIFIED TRIGONOMETRIC INTERPOLATOR

INTERPOLATION ERRORS ARE SHOWN IN HATCH

*FIG. 16A*
LAGRANGE CUBIC

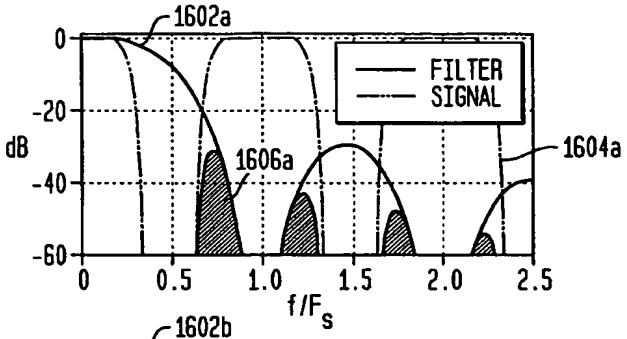



*FIG. 16B*
TRIGONOMETRIC INTERPOLATOR 1000
(FIG. 10)

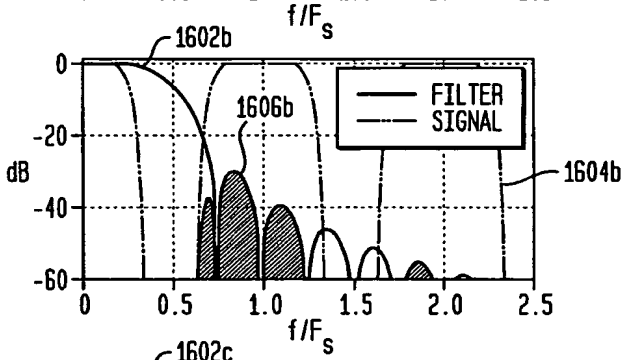



*FIG. 16C*
TRIGONOMETRIC INTERPOLATOR 1400
(FIG. 14)

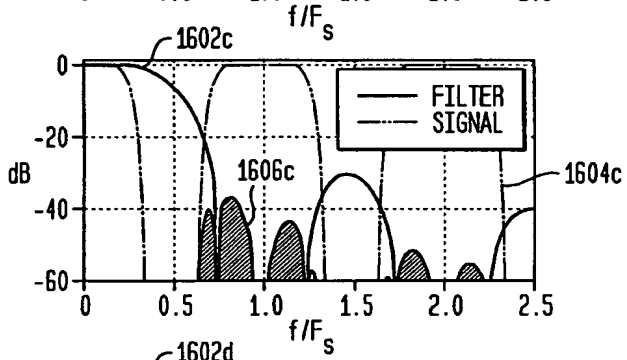



*FIG. 16D*
OPTIMAL STRUCTURE

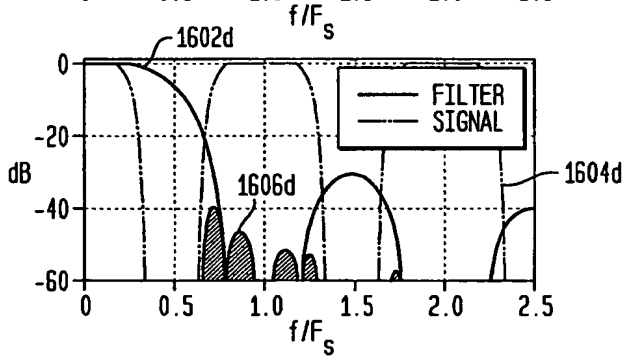


FIG. 17

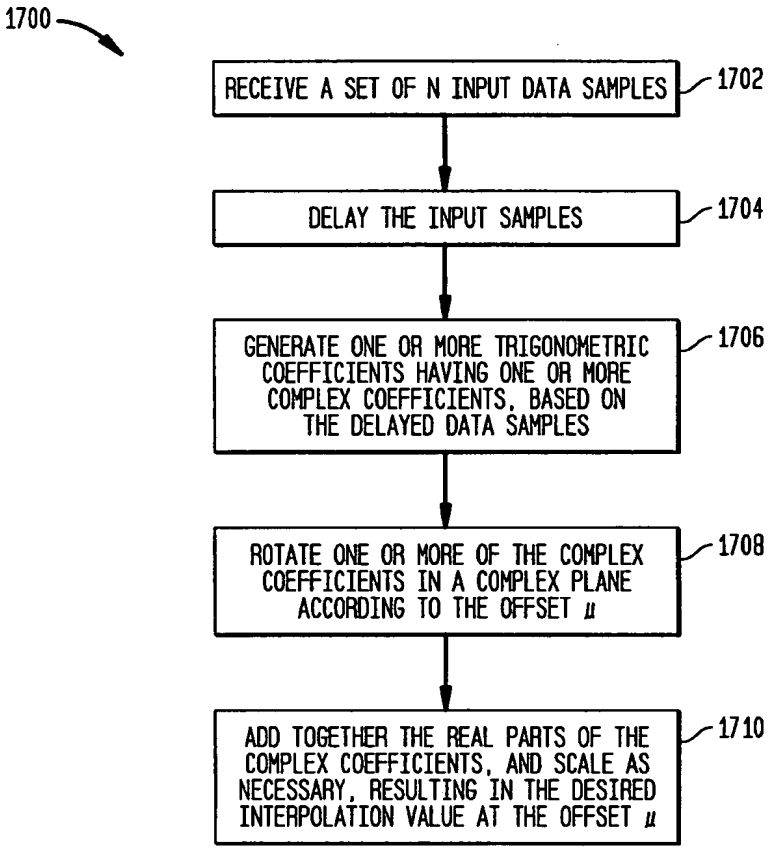

1700
RECEIVE A SET OF N INPUT DATA SAMPLES
1702
DELAY THE INPUT SAMPLES
1704
GENERATE ONE OR MORE TRIGONOMETRIC COEFFICIENTS HAVING ONE OR MORE COMPLEX COEFFICIENTS, BASED ON THE DELAYED DATA SAMPLES
1706
ROTATE ONE OR MORE OF THE COMPLEX COEFFICIENTS IN A COMPLEX PLANE ACCORDING TO THE OFFSET μ
1708
ADD TOGETHER THE REAL PARTS OF THE COMPLEX COEFFICIENTS, AND SCALE AS NECESSARY, RESULTING IN THE DESIRED INTERPOLATION VALUE AT THE OFFSET μ
1710

FIG. 18

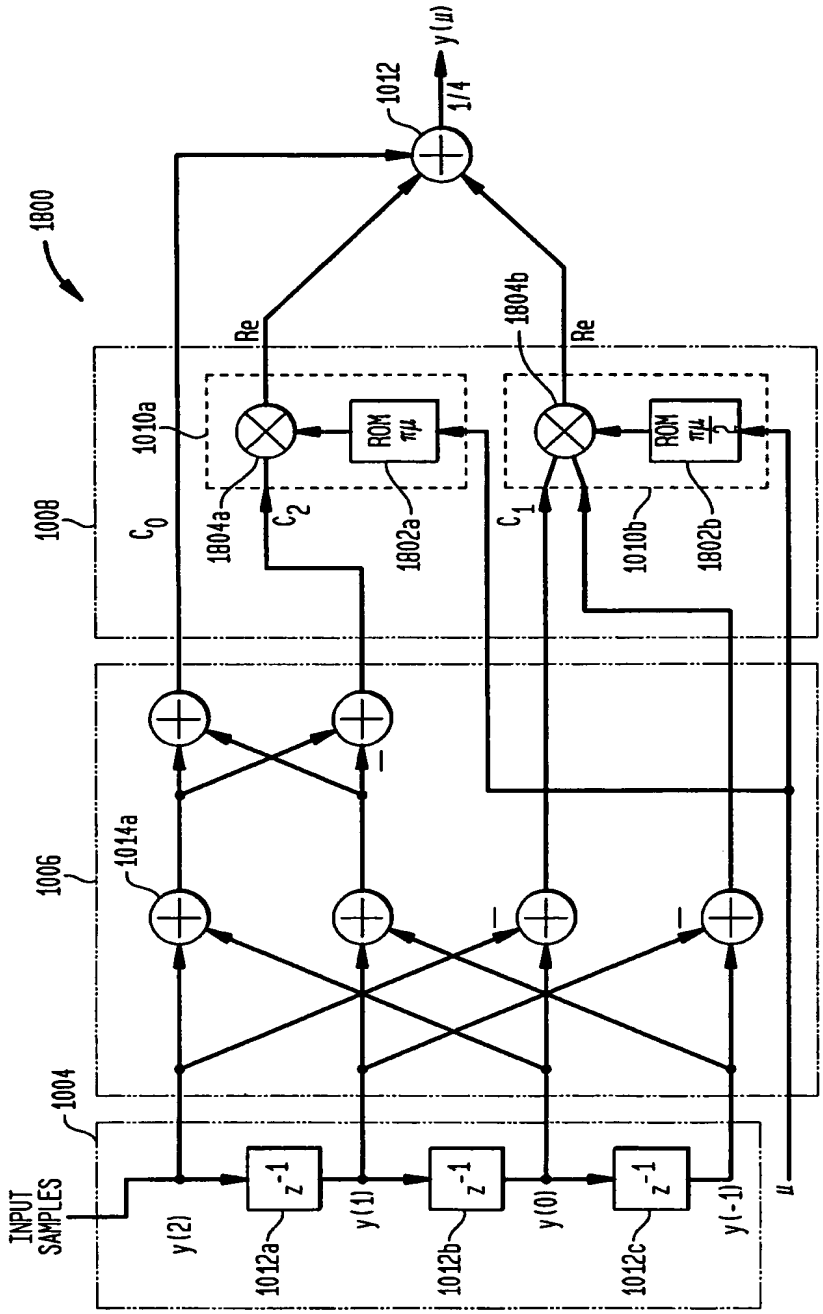

1800
1012
1/4
y(μ)
Re
Re
1804b
1010a
ROM
πμ
ROM
πμ/2
1008
C0
C2
C1
1804a
1802a
1010b
1802b
1006
1014a
1004
INPUT SAMPLES
y(2)
y(1)
y(0)
y(-1)
z-1
1012a
1012b
1012c
μ

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FIG. 19

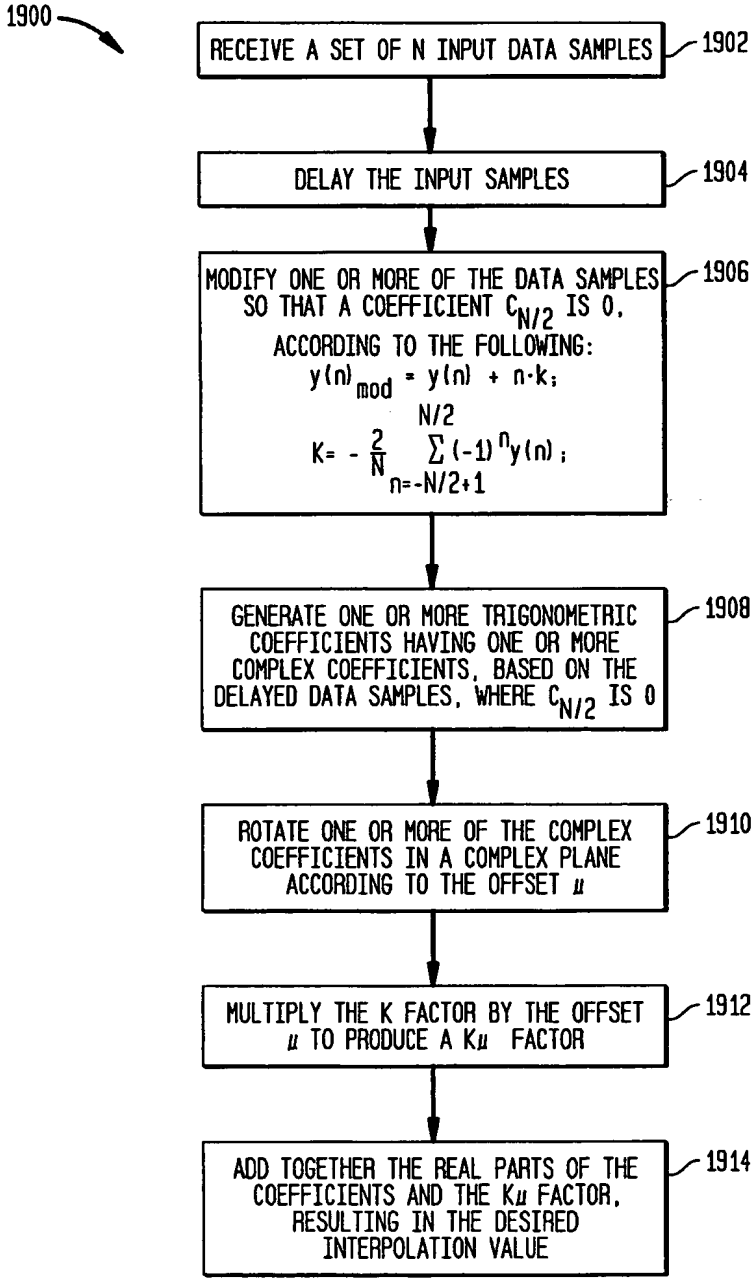


*FIG. 20A*

NORMALIZED IMPULSE RESPONSES
f OF THE INTERPOLATION FILTERS

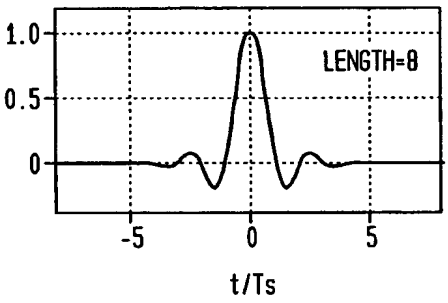



*FIG. 20B*

NORMALIZED IMPULSE RESPONSES
f OF THE INTERPOLATION FILTERS

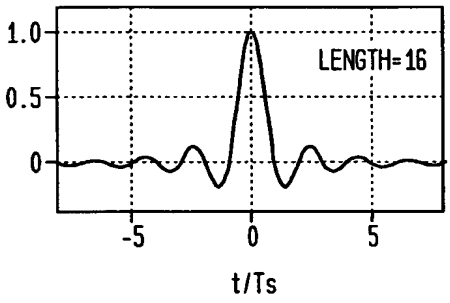



*FIG. 21A*

NORMALIZED FREQUENCY RESPONSES
F OF THE INTERPOLATION FILTERS

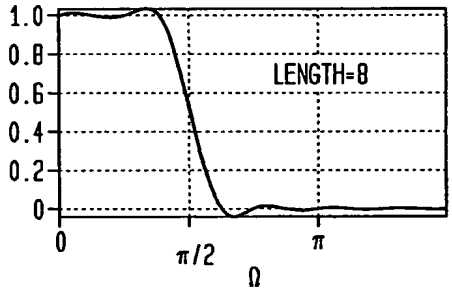



*FIG. 21B*

NORMALIZED FREQUENCY RESPONSES
F OF THE INTERPOLATION FILTERS

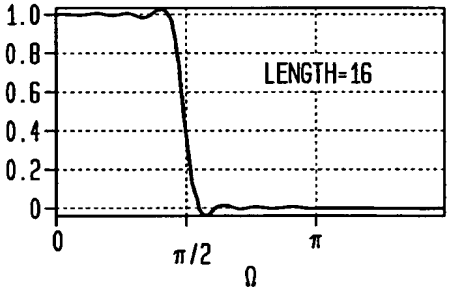


FIG. 22
ANALYSIS OF THE FREQUENCY RESPONSES

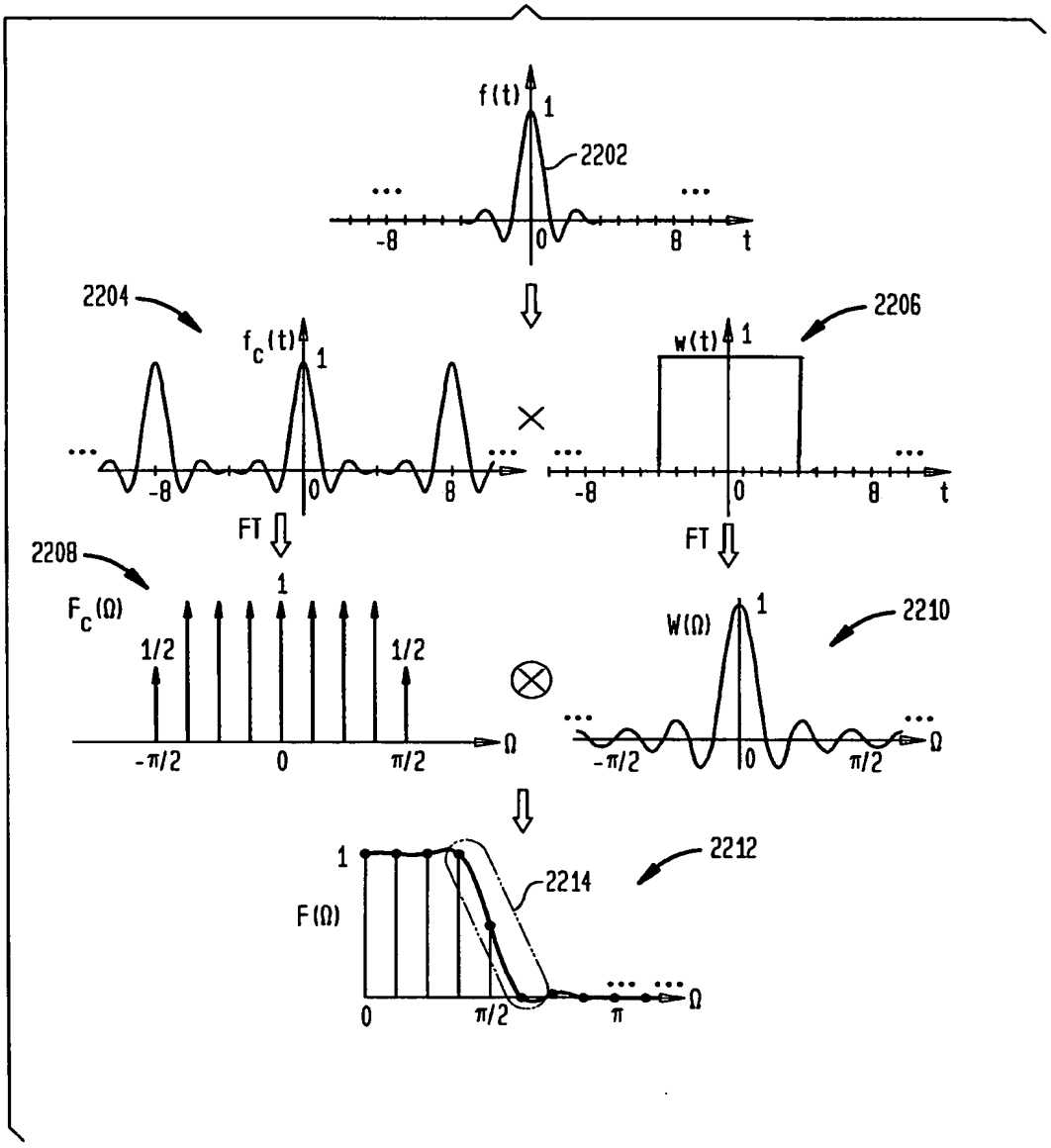


FIG. 23A
EFFECT OF A MORE GRADUAL TRANSITION AT THE BAND EDGE

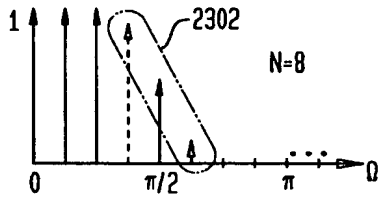



FIG. 23B
EFFECT OF A MORE GRADUAL TRANSITION AT THE BAND EDGE

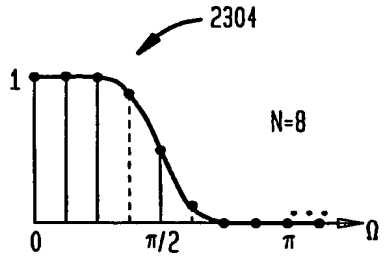



FIG. 24
REDUCING THE TRANSITION BANDWIDTH BY INCREASING N

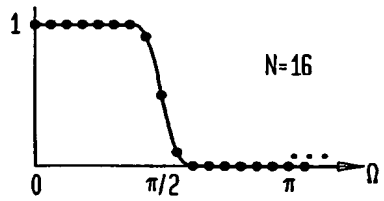


FIG. 25A
IMPULSE RESPONSE OF THE ORIGINAL FILTER AND THE MODIFIED FILTER

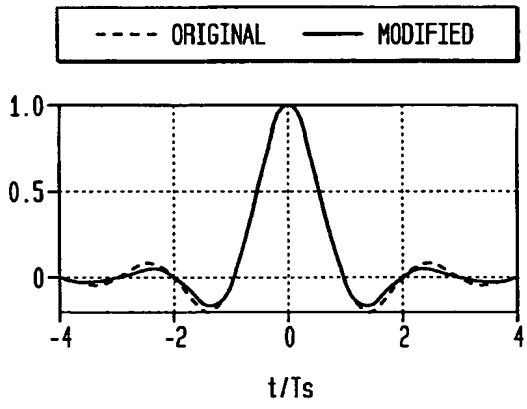



FIG. 25B
THE EQUIVALENT WINDOW

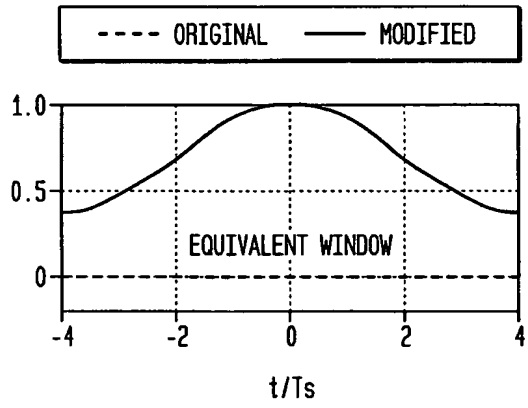


FIG. 26

FORMING THE FREQUENCY RESPONSE OF THE DISCRETE-TIME FRACTIONAL-DELAY FILTER

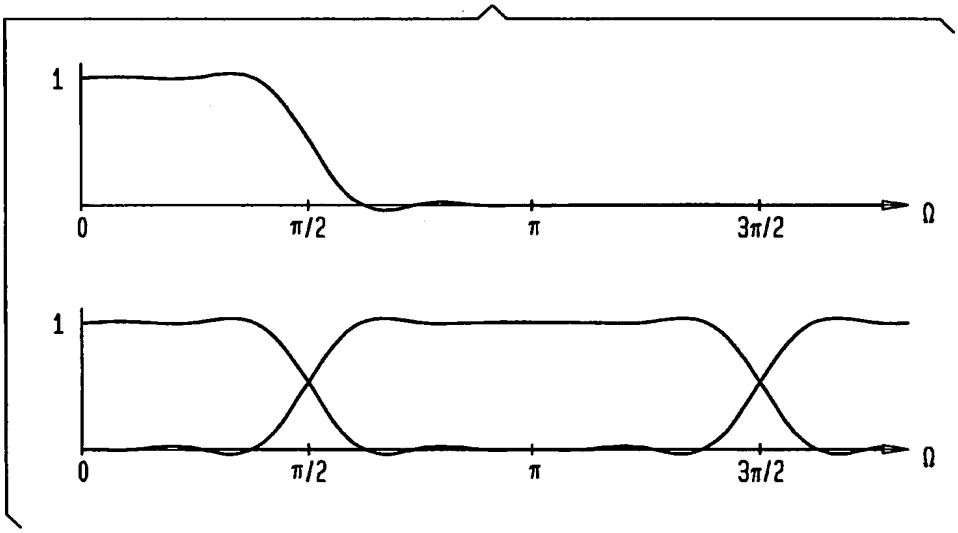



FIG. 27A

FRACTIONAL-DELAY FILTER WITH $\mu$=0.12, USING THE PRELIMINARY N=8 INTERPOLATOR

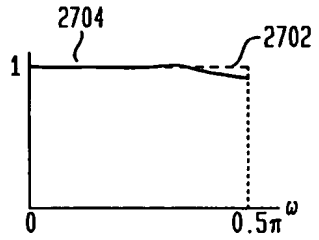



FIG. 27B

FRACTIONAL-DELAY FILTER WITH $\mu$=0.5, USING THE PRELIMINARY N-8 INTERPOLATOR

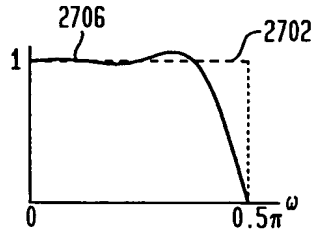
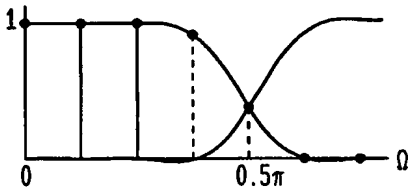
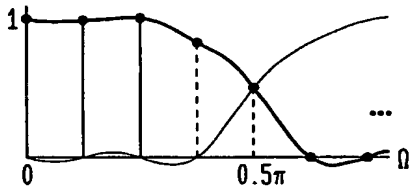


FIG. 28A



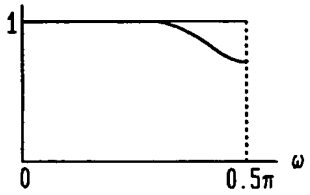

μ=0.12

FIG. 28B



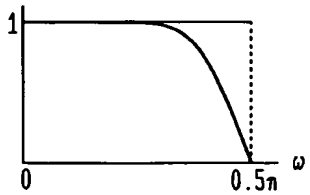

μ=0.5

FIG. 28C




μ=0.12

FIG. 28D




μ=0.5

FIG. 29A

$F_{\mu}(\omega)$, WITH $\mu$=0.5, N=8, BEFORE OPTIMIZATION

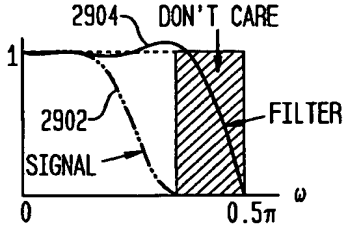



FIG. 29B

$F_{\mu}(\omega)$, WITH $\mu$=0.5, N=8, AFTER OPTIMIZATION

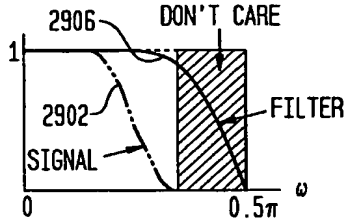



FIG. 30A

$F_{\mu}(\omega)$, WITH $\mu$=0.5, N=4, BEFORE MODIFICATION

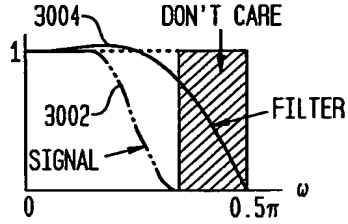



FIG. 30B

$F_{\mu}(\omega)$, WITH $\mu$=0.5, N=4, AFTER MODIFICATION

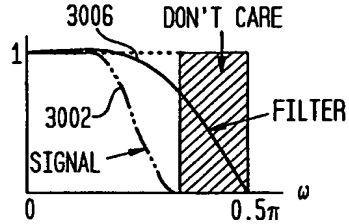


FIG. 31A

$F_\mu(\omega)$, $\mu$=0.5, SIMPLIFIED N=4 STRUCTURE BEFORE MODIFICATION

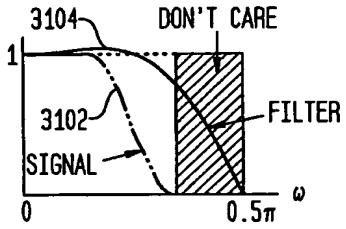



FIG. 31B

$F_\mu(\omega)$, $\mu$=0.5, SIMPLIFIED N=4 STRUCTURE AFTER MODIFICATION

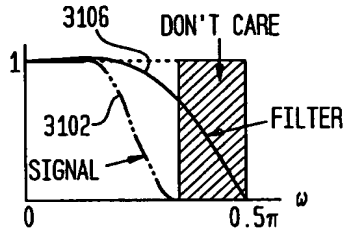



FIG. 32

REAL AND IMAGINARY COMPONENTS OF THE $F_\mu(1)e^{j\frac{\pi}{2}\mu}$ VALUE

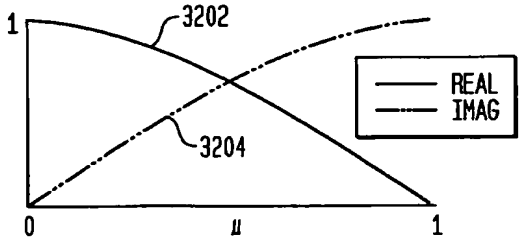



FIG. 33

SIGNAL WITH TWO SAMPLES/SYMBOL AND 40% EXCESS BANDWIDTH

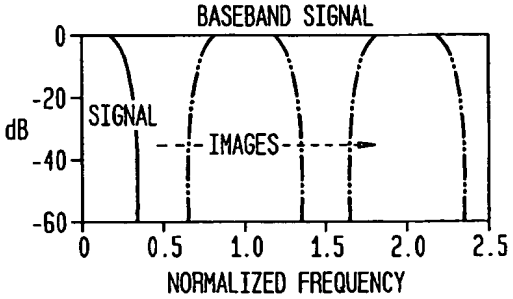


FIG. 34

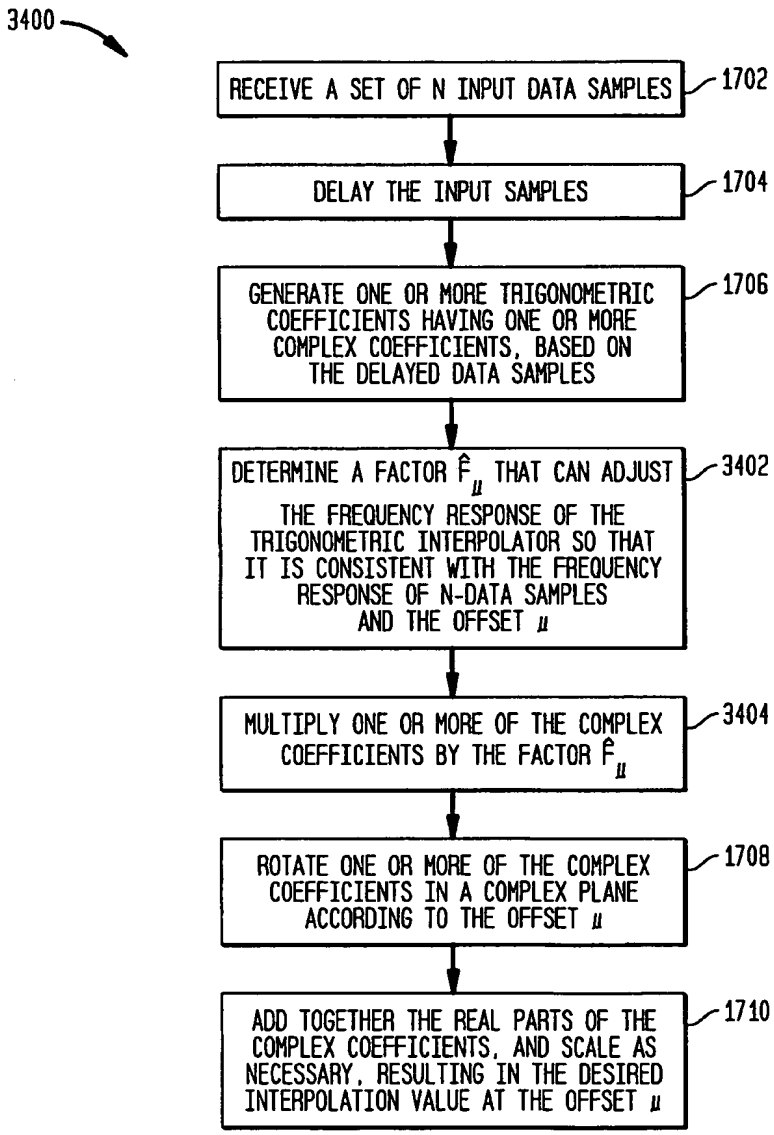
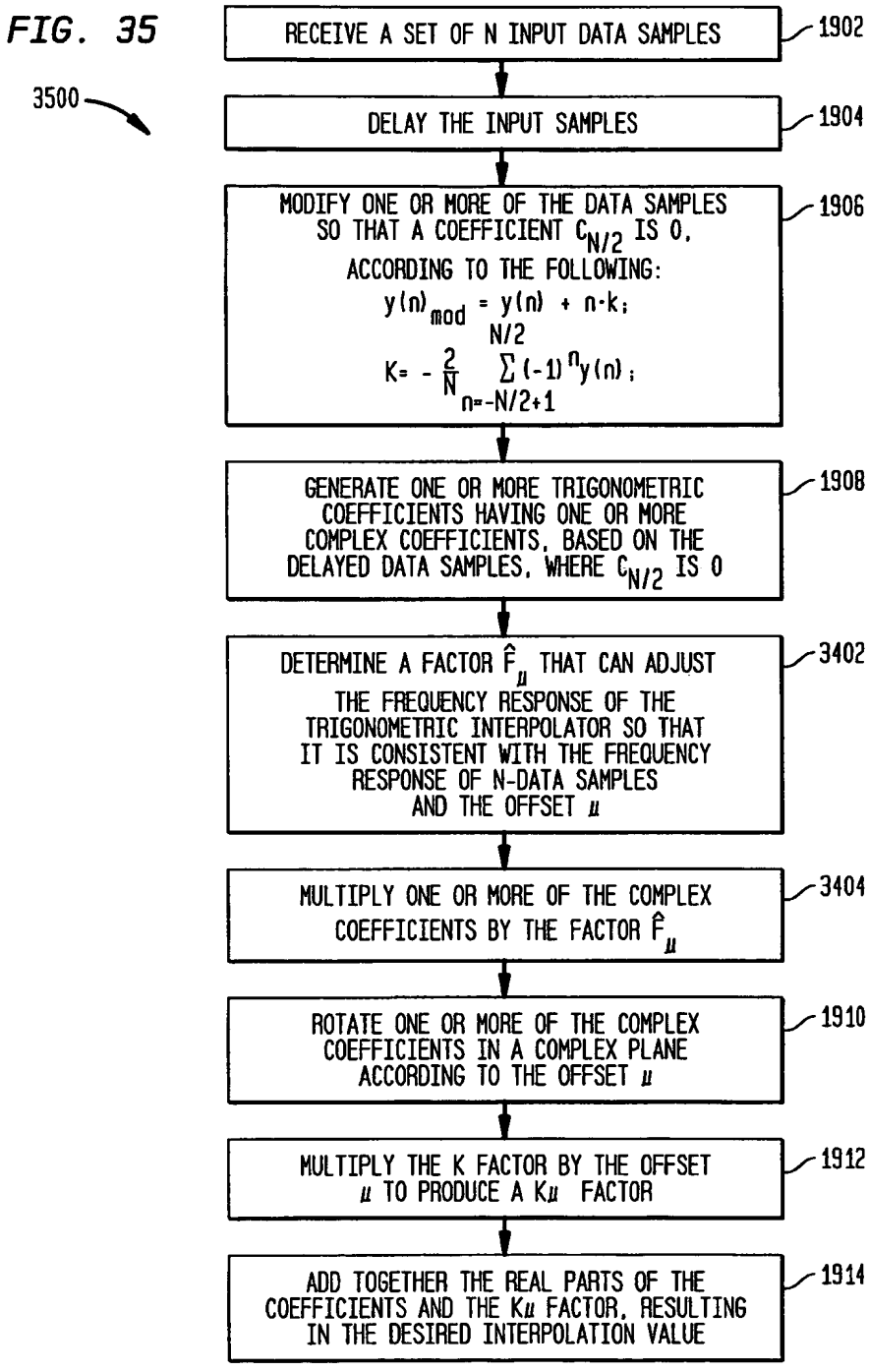

3400
RECEIVE A SET OF N INPUT DATA SAMPLES
1702
DELAY THE INPUT SAMPLES
1704
GENERATE ONE OR MORE TRIGONOMETRIC COEFFICIENTS HAVING ONE OR MORE COMPLEX COEFFICIENTS, BASED ON THE DELAYED DATA SAMPLES
1706
DETERMINE A FACTOR $\hat{F}_{\mu}$ THAT CAN ADJUST THE FREQUENCY RESPONSE OF THE TRIGONOMETRIC INTERPOLATOR SO THAT IT IS CONSISTENT WITH THE FREQUENCY RESPONSE OF N-DATA SAMPLES AND THE OFFSET $\mu$
3402
MULTIPLY ONE OR MORE OF THE COMPLEX COEFFICIENTS BY THE FACTOR $\hat{F}_{\mu}$
3404
ROTATE ONE OR MORE OF THE COMPLEX COEFFICIENTS IN A COMPLEX PLANE ACCORDING TO THE OFFSET $\mu$
1708
ADD TOGETHER THE REAL PARTS OF THE COMPLEX COEFFICIENTS, AND SCALE AS NECESSARY, RESULTING IN THE DESIRED INTERPOLATION VALUE AT THE OFFSET $\mu$
1710

FIG. 35


3500
RECEIVE A SET OF N INPUT DATA SAMPLES
1902
DELAY THE INPUT SAMPLES
1904
MODIFY ONE OR MORE OF THE DATA SAMPLES SO THAT A COEFFICIENT $C_{N/2}$ IS 0, ACCORDING TO THE FOLLOWING:
$y(n)_{mod} = y(n) + n \cdot k;$
$K = -\frac{2}{N} \sum_{n=-N/2+1}^{N/2} (-1)^n y(n);$
1906
GENERATE ONE OR MORE TRIGONOMETRIC COEFFICIENTS HAVING ONE OR MORE COMPLEX COEFFICIENTS, BASED ON THE DELAYED DATA SAMPLES, WHERE $C_{N/2}$ IS 0
1908
DETERMINE A FACTOR $\hat{F}_\mu$ THAT CAN ADJUST THE FREQUENCY RESPONSE OF THE TRIGONOMETRIC INTERPOLATOR SO THAT IT IS CONSISTENT WITH THE FREQUENCY RESPONSE OF N-DATA SAMPLES AND THE OFFSET $\mu$
3402
MULTIPLY ONE OR MORE OF THE COMPLEX COEFFICIENTS BY THE FACTOR $\hat{F}_\mu$
3404
ROTATE ONE OR MORE OF THE COMPLEX COEFFICIENTS IN A COMPLEX PLANE ACCORDING TO THE OFFSET $\mu$
1910
MULTIPLY THE K FACTOR BY THE OFFSET $\mu$ TO PRODUCE A $K\mu$ FACTOR
1912
ADD TOGETHER THE REAL PARTS OF THE COEFFICIENTS AND THE $K\mu$ FACTOR, RESULTING IN THE DESIRED INTERPOLATION VALUE
1914

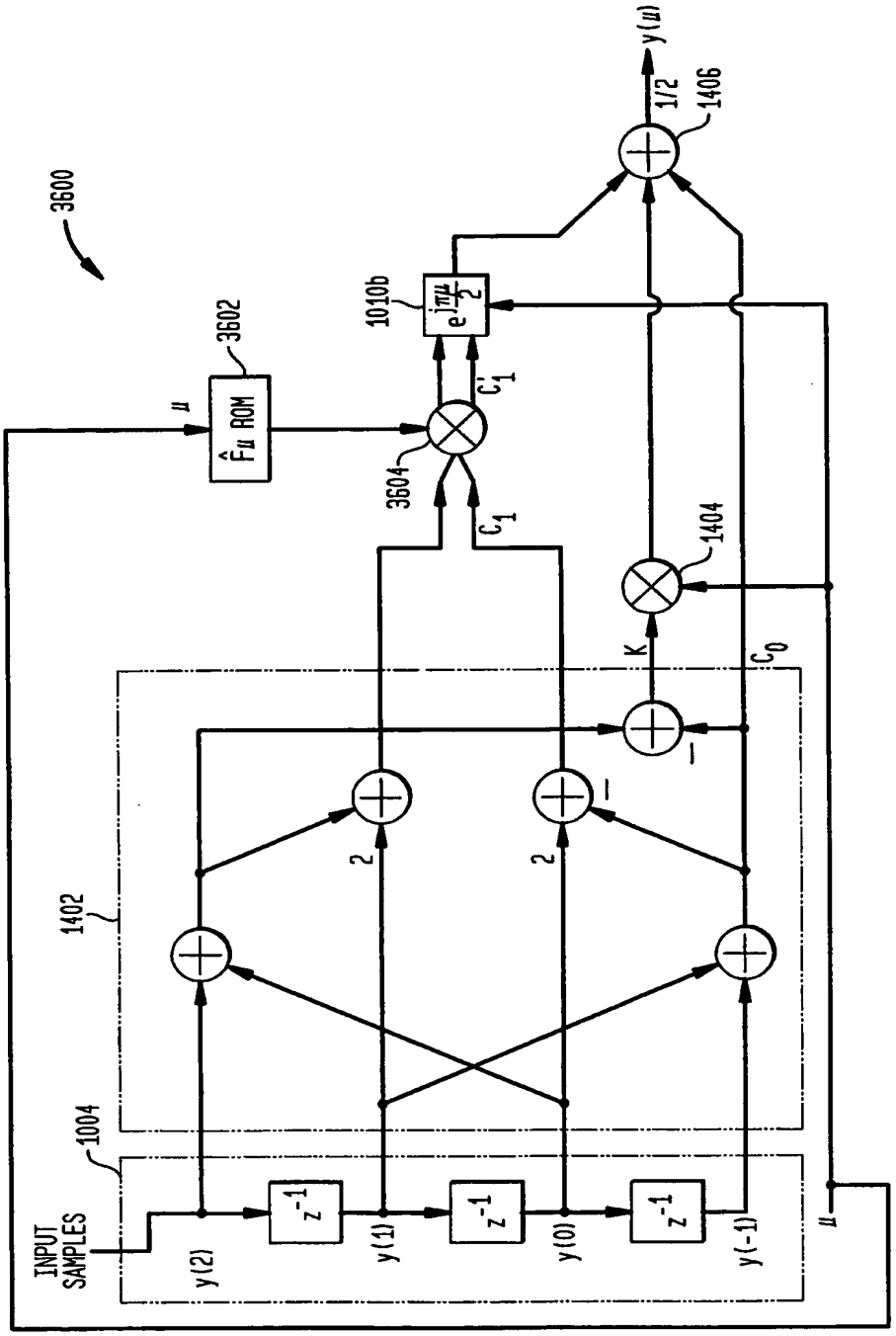



FIG. 36
THE OPTIMIZED STRUCTURE FOR N=4

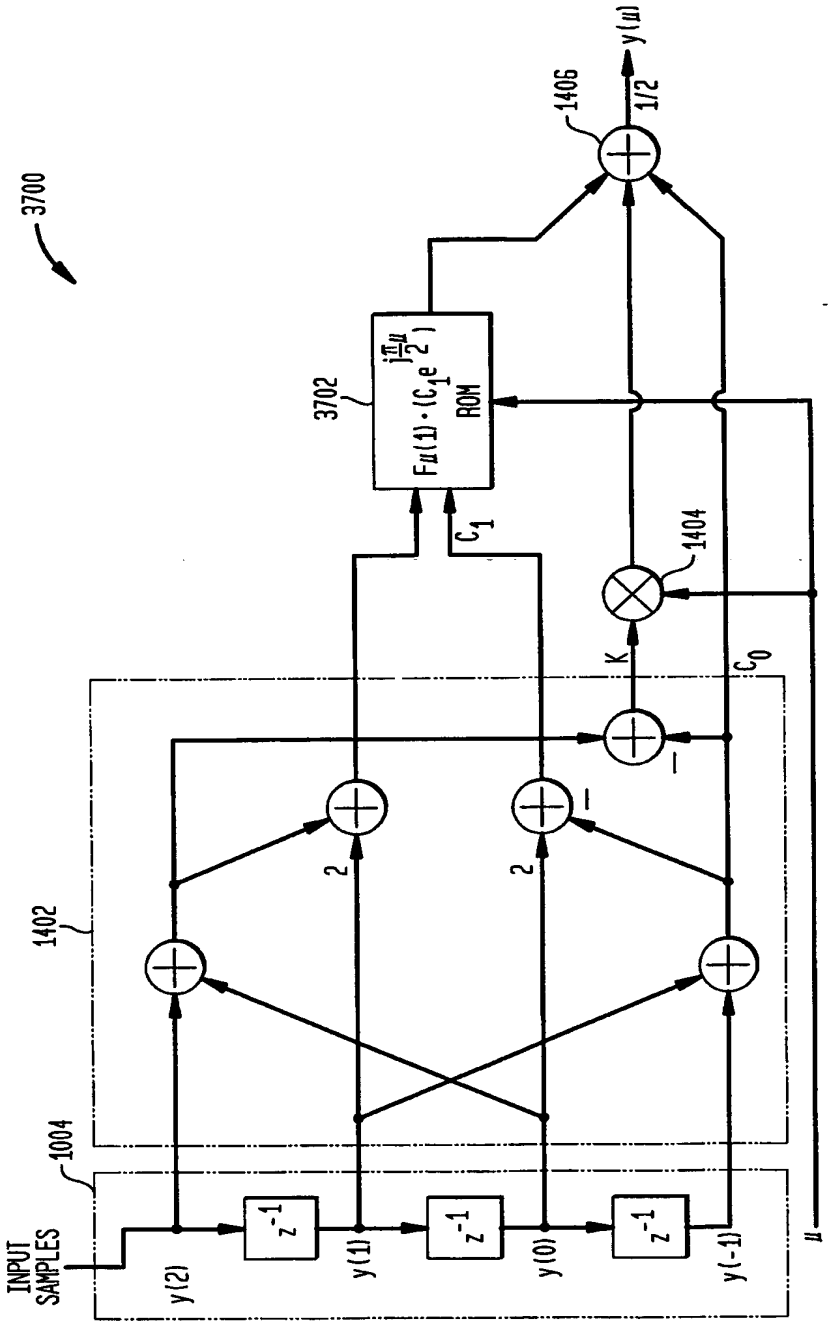



FIG. 37
THE OPTIMIZED STRUCTURE FOR N=4

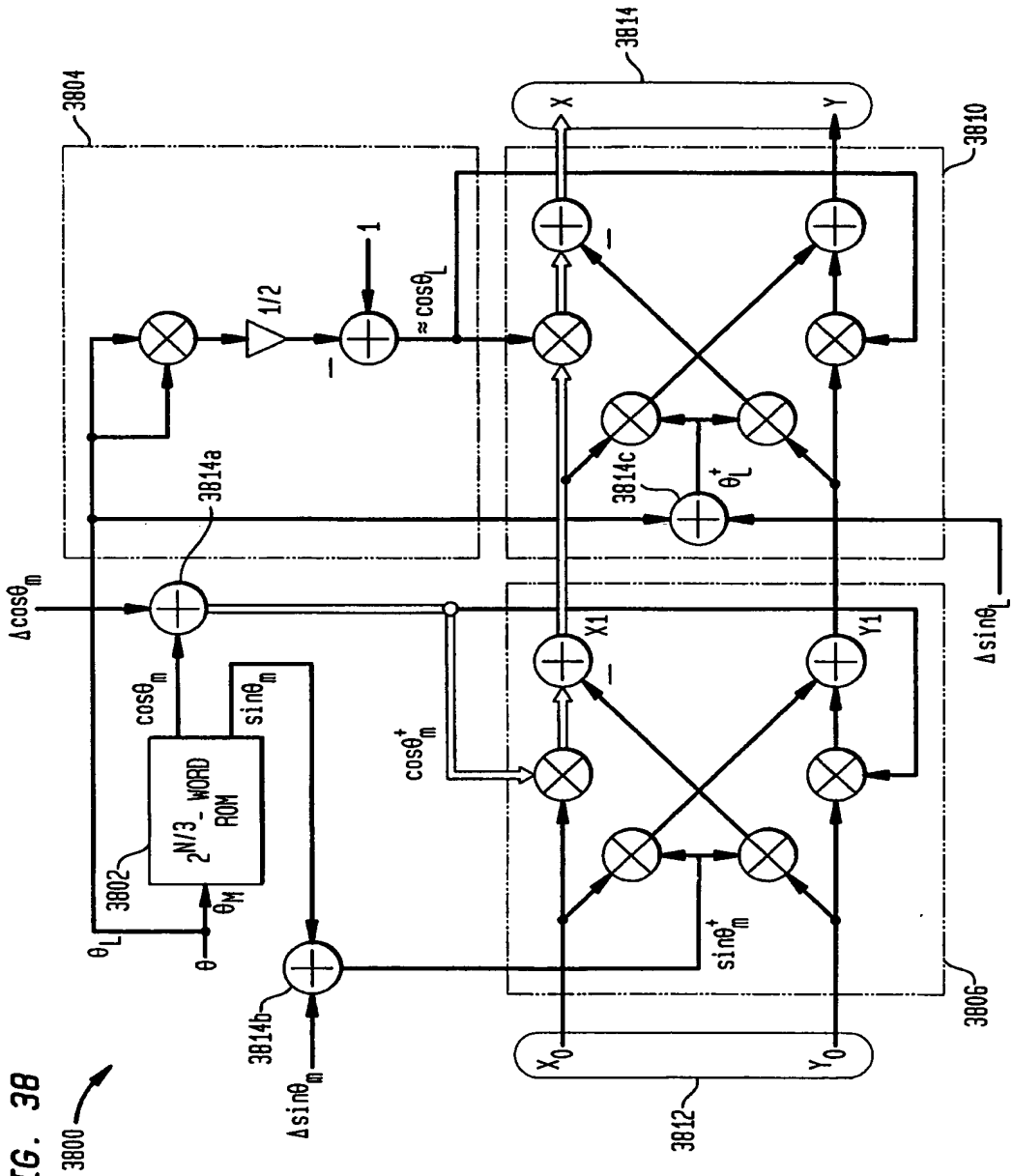

3800
3804
3814
3810
3812
3806
3802
3814a
3814b
3814c
X
Y
X1
Y1
X0
Y0
1/2
1
≈cosθL
Δcosθm
Δsinθm
ΔsinθL
cosθm
sinθm
cos+θm
sin+θm
θL+
θL
θ
θM
2N/3 WORD ROM

FIG. 38

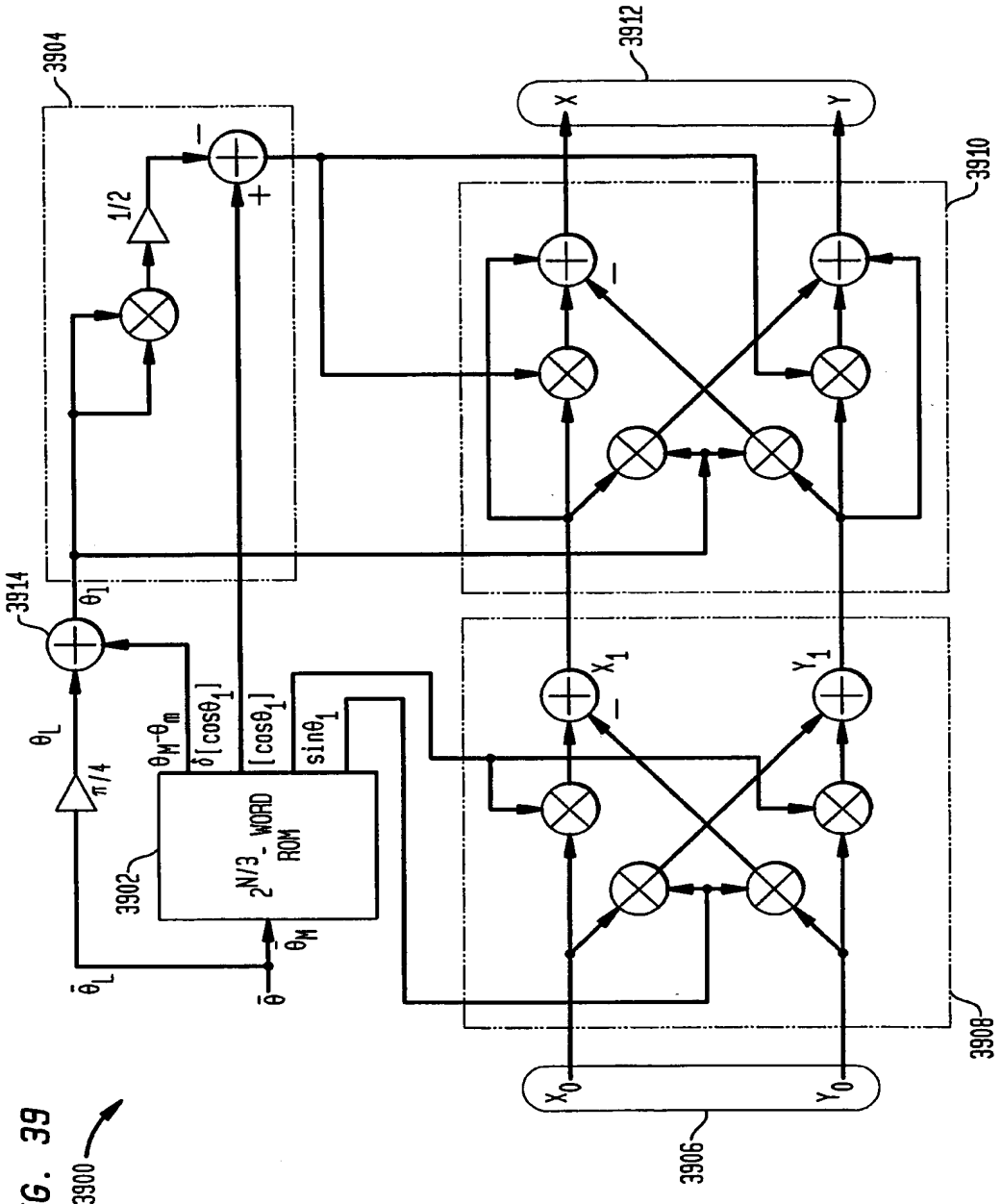

3904
3912
X
Y
3910
1/2
−
+
3914
θ1
θL
π/4
θM-θm
δ[cosθ1]
[cosθ1]
sinθ1
2N/3 - WORD ROM
3902
θM
θ̄L
θ̄
X1
Y1
X0
Y0
3908
3906
3900

FIG. 39

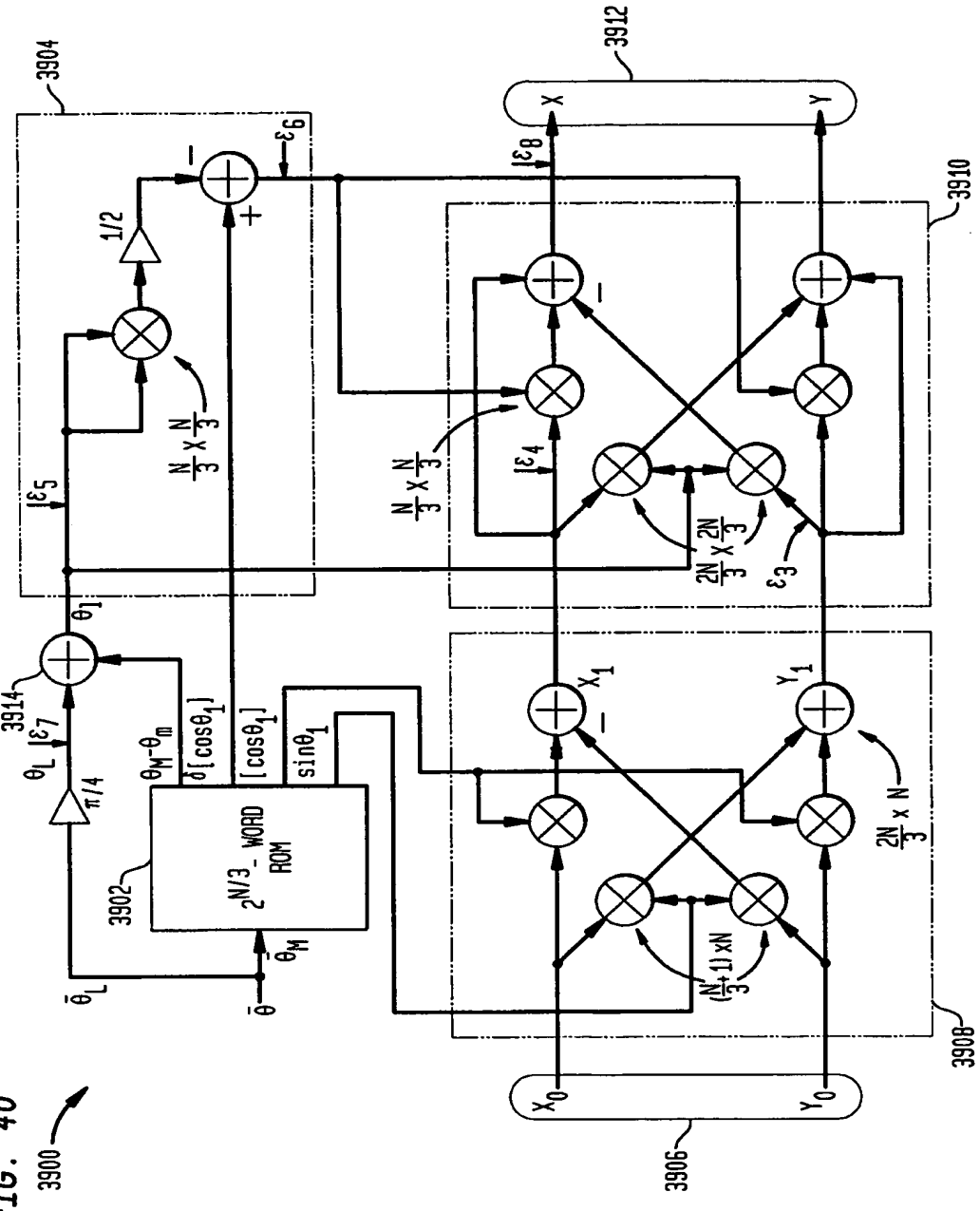
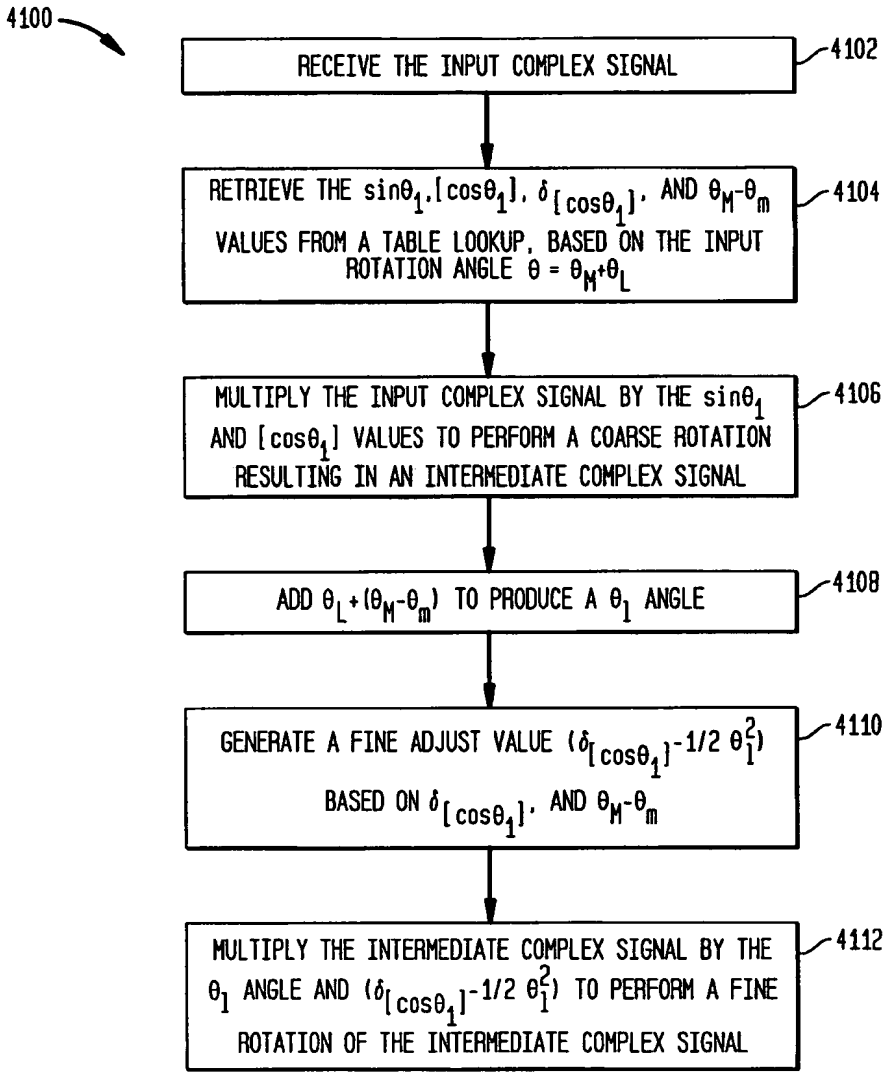

3900
3902
3904
3906
3908
3910
3912
3914
2N/3- WORD ROM
1/2
π/4
X
Y
X0
Y0
X1
Y1
ε3
ε4
ε5
ε6
ε7
ε8
θL
θM
θ1
θM-θm
δ[cosθ1]
[cosθ1]
sinθ1
N/3 x N/3
2N/3 x 2N/3
2N/3 x N
(N/3+1) xN

FIG. 40

FIG. 41


4100
RECEIVE THE INPUT COMPLEX SIGNAL
4102
RETRIEVE THE $\sin\theta_1$,$[\cos\theta_1]$, $\delta_{[\cos\theta_1]}$, AND $\theta_M$-$\theta_m$ VALUES FROM A TABLE LOOKUP, BASED ON THE INPUT ROTATION ANGLE $\theta = \theta_M+\theta_L$
4104
MULTIPLY THE INPUT COMPLEX SIGNAL BY THE $\sin\theta_1$ AND $[\cos\theta_1]$ VALUES TO PERFORM A COARSE ROTATION RESULTING IN AN INTERMEDIATE COMPLEX SIGNAL
4106
ADD $\theta_L+(\theta_M-\theta_m)$ TO PRODUCE A $\theta_1$ ANGLE
4108
GENERATE A FINE ADJUST VALUE $(\delta_{[\cos\theta_1]}-1/2\ \theta_1^2)$ BASED ON $\delta_{[\cos\theta_1]}$, AND $\theta_M$-$\theta_m$
4110
MULTIPLY THE INTERMEDIATE COMPLEX SIGNAL BY THE $\theta_1$ ANGLE AND $(\delta_{[\cos\theta_1]}-1/2\ \theta_1^2)$ TO PERFORM A FINE ROTATION OF THE INTERMEDIATE COMPLEX SIGNAL
4112

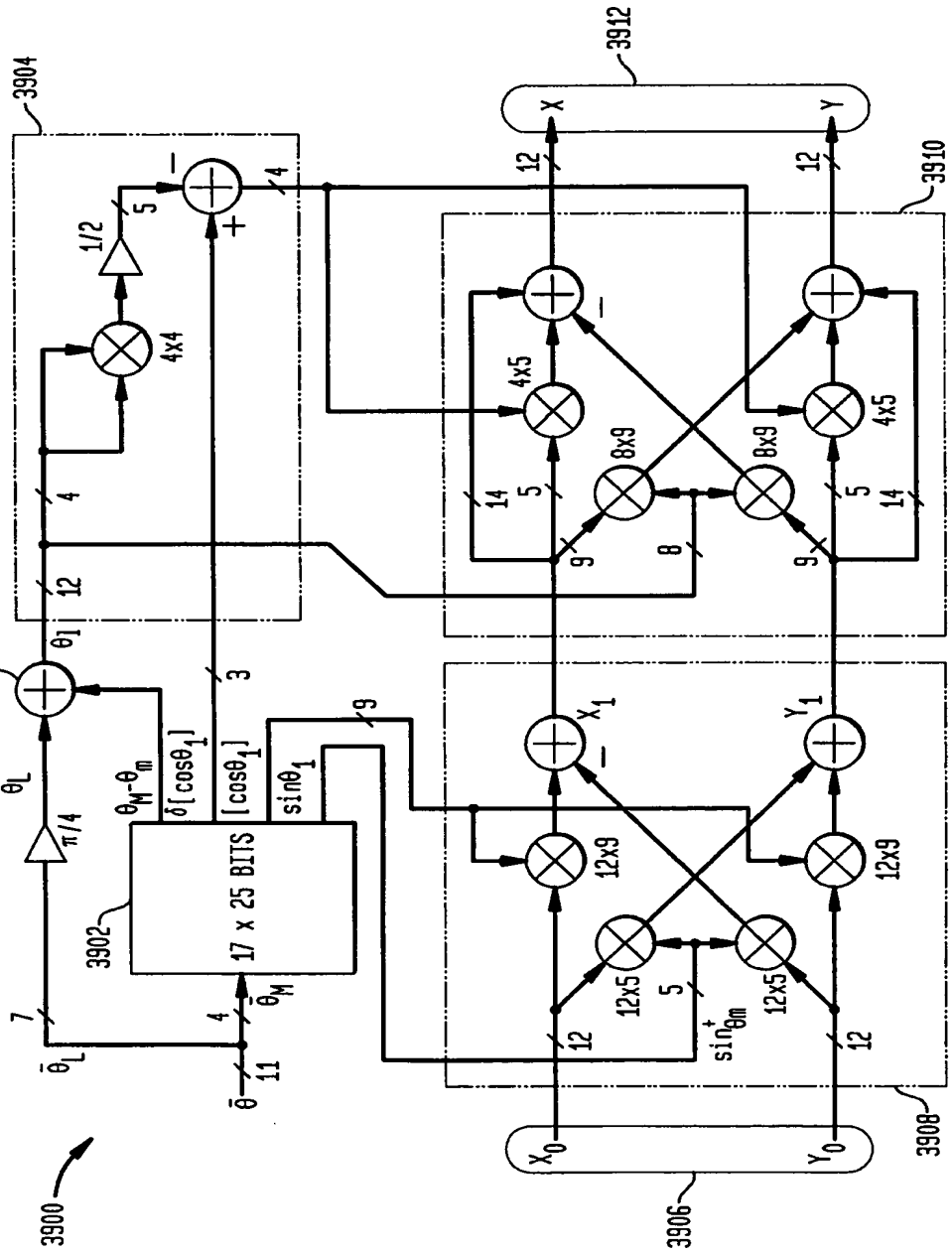
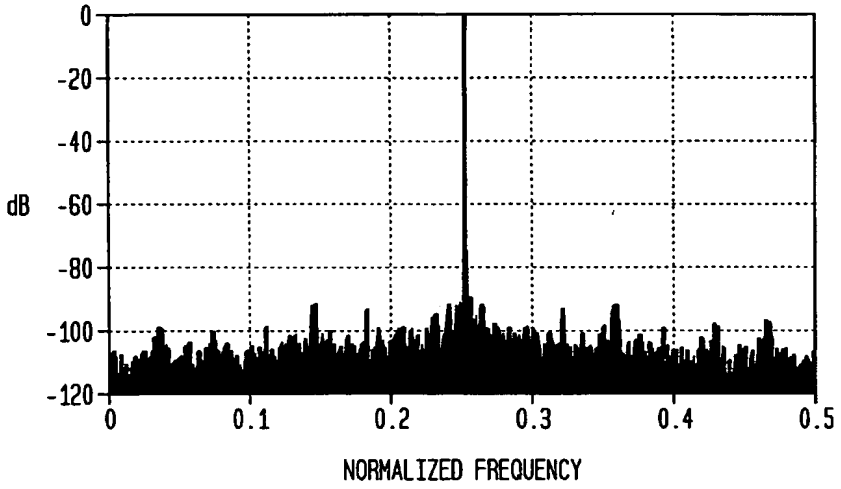



FIG. 42
THE INTERNAL WORDLENGTH OF THE STRUCTURE THAT ACHIEVED 90.36 db SFDR

*FIG. 43*

OUTPUT SPECTRUM SHOWING 90.36 dB SFDR



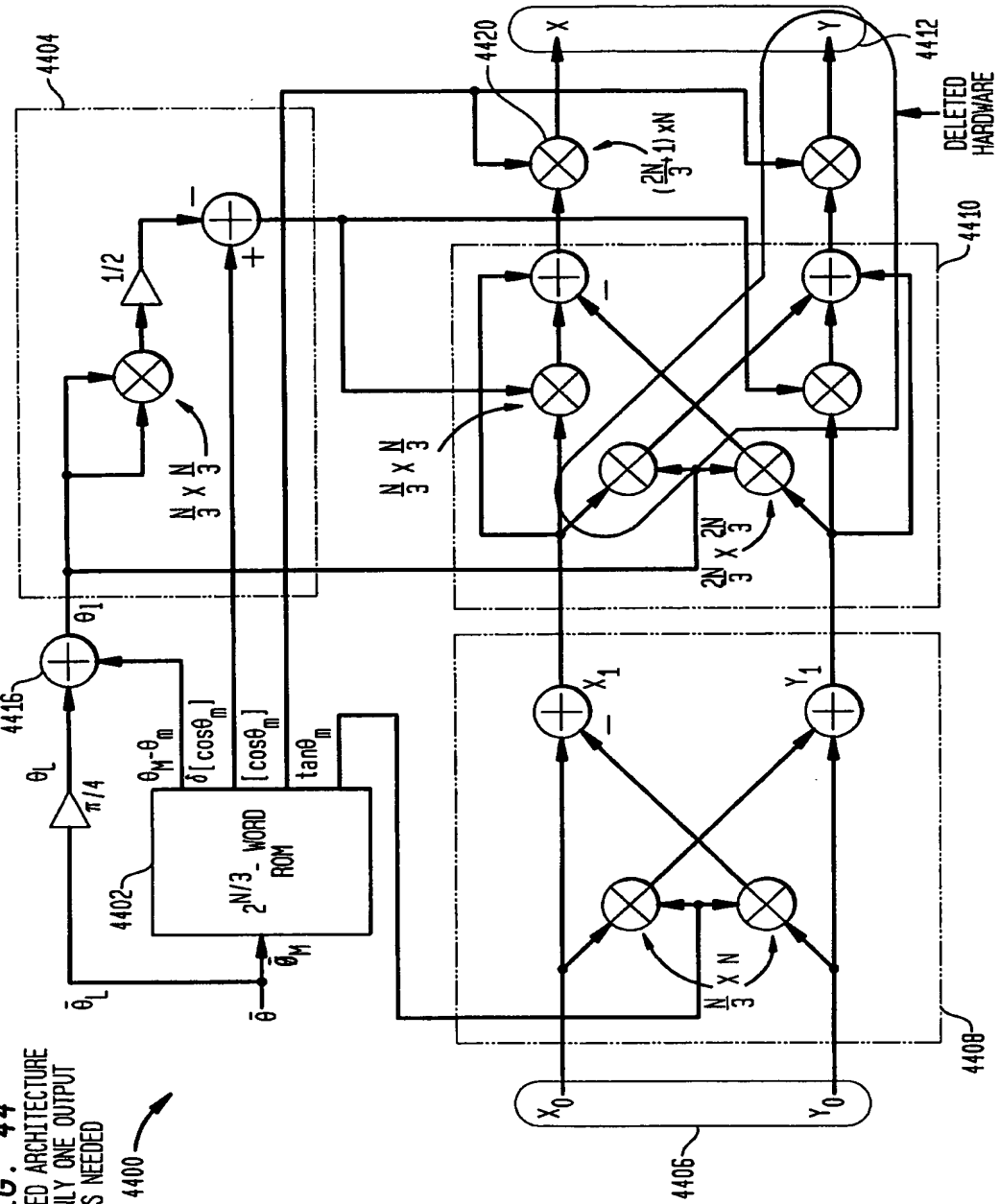



FIG. 44
A MODIFIED ARCHITECTURE WHEN ONLY ONE OUTPUT IS NEEDED

4400

FIG. 45

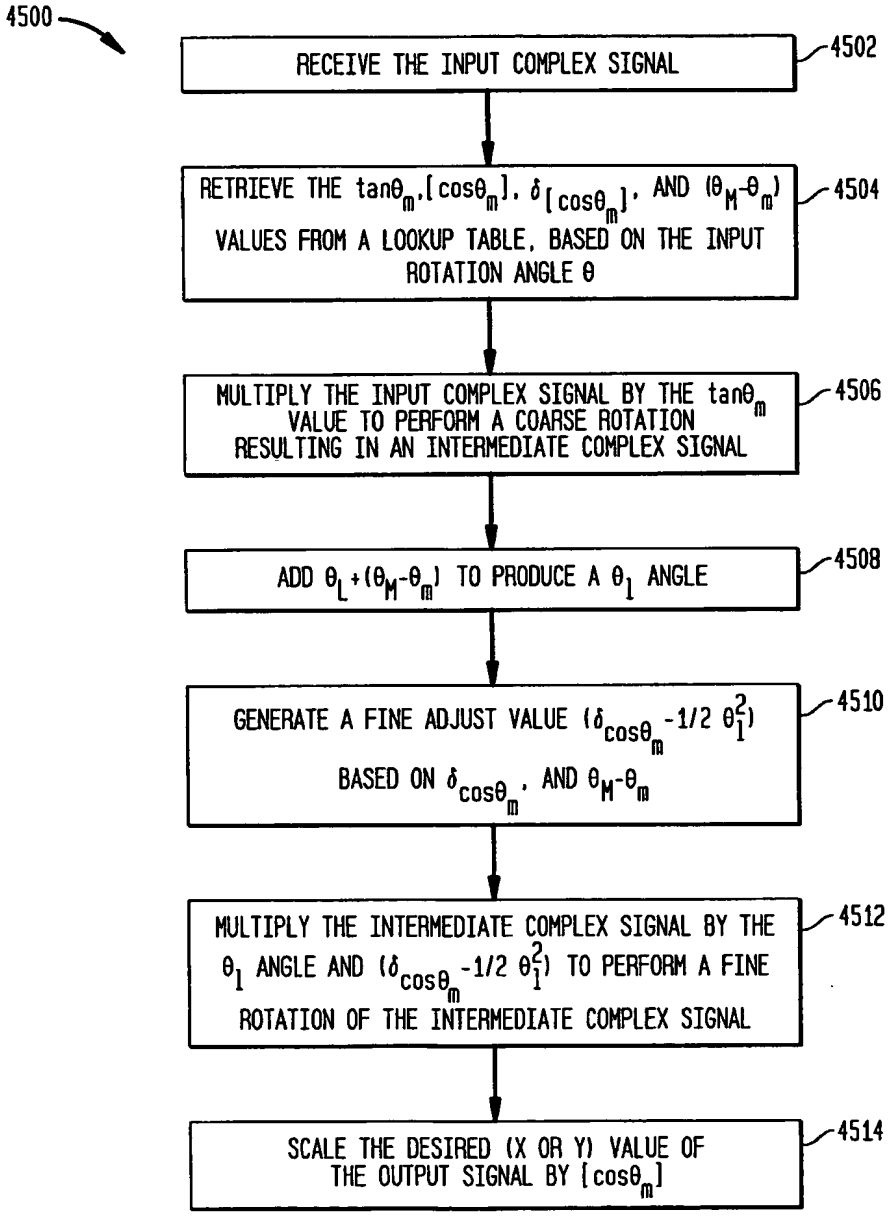
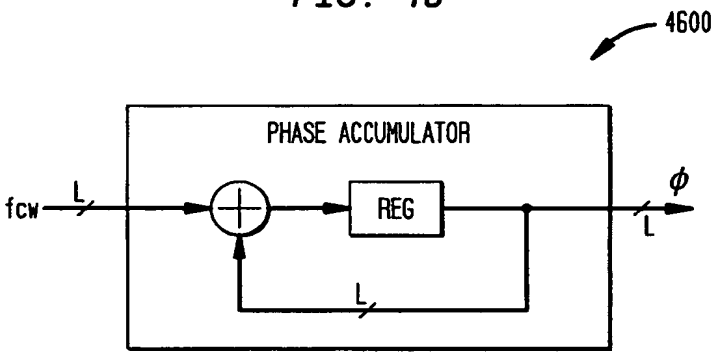

4500
RECEIVE THE INPUT COMPLEX SIGNAL
4502
RETRIEVE THE tanθm,[cosθm], δ[cosθm], AND (θM-θm) VALUES FROM A LOOKUP TABLE, BASED ON THE INPUT ROTATION ANGLE θ
4504
MULTIPLY THE INPUT COMPLEX SIGNAL BY THE tanθm VALUE TO PERFORM A COARSE ROTATION RESULTING IN AN INTERMEDIATE COMPLEX SIGNAL
4506
ADD θL+(θM-θm) TO PRODUCE A θ1 ANGLE
4508
GENERATE A FINE ADJUST VALUE (δcosθm -1/2 θ1²) BASED ON δcosθm, AND θM-θm
4510
MULTIPLY THE INTERMEDIATE COMPLEX SIGNAL BY THE θ1 ANGLE AND (δcosθm -1/2 θ1²) TO PERFORM A FINE ROTATION OF THE INTERMEDIATE COMPLEX SIGNAL
4512
SCALE THE DESIRED (X OR Y) VALUE OF THE OUTPUT SIGNAL BY [cosθm]
4514

FIG. 46




WHERE THE ADDER IS AN OVERFLOWING ACCUMULATOR

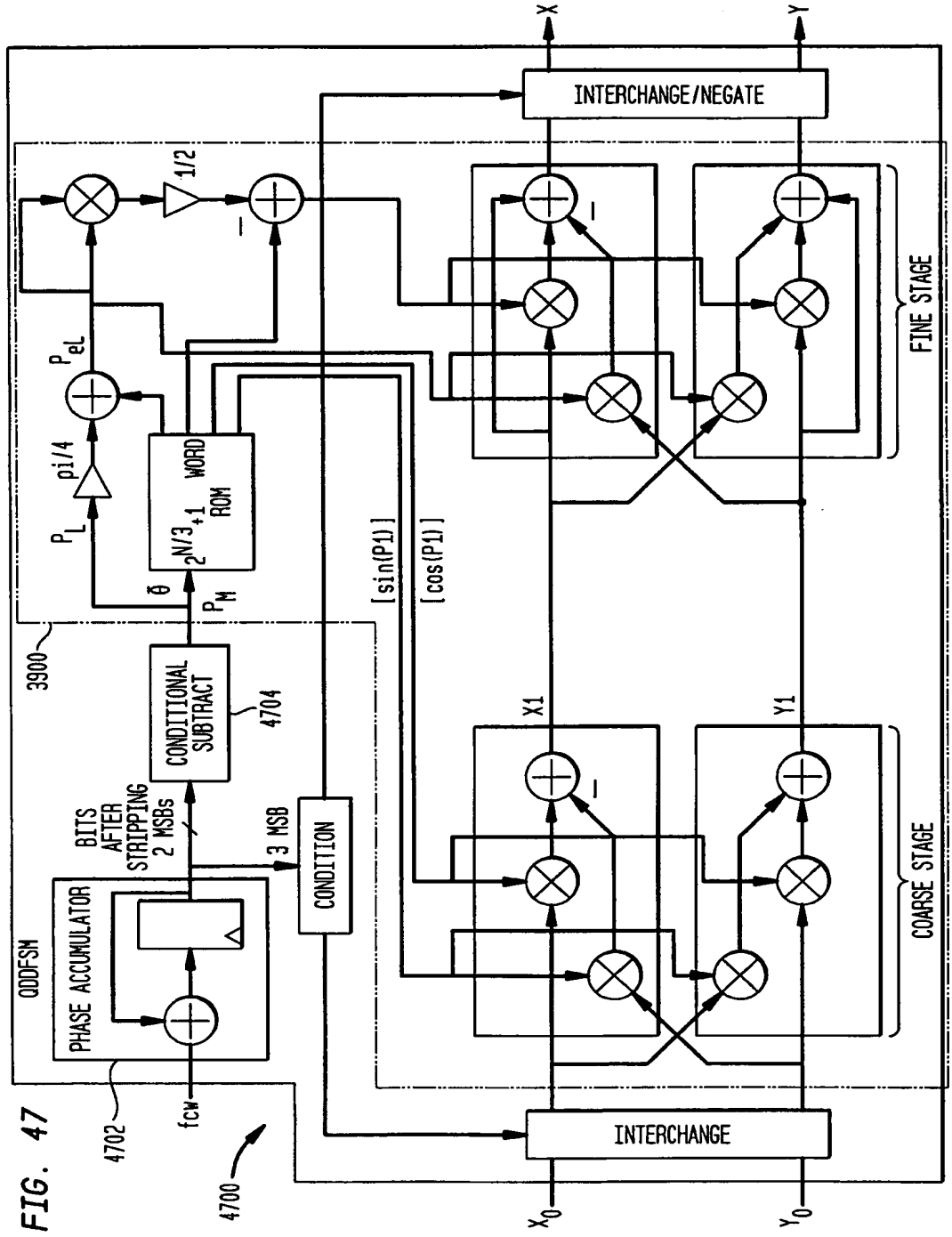

X
Y
INTERCHANGE/NEGATE
1/2
FINE STAGE
$P_{eL}$
pi/4
$P_L$
$2^{N/3+1}$ WORD ROM
θ
$P_M$
[sin(P1)]
[cos(P1)]
3900
CONDITIONAL SUBTRACT
4704
X1
Y1
BITS AFTER STRIPPING 2 MSBs
3 MSB
CONDITION
COARSE STAGE
ODDFSM
PHASE ACCUMULATOR
fcw
4702
4700
INTERCHANGE
$X_0$
$Y_0$

FIG. 47

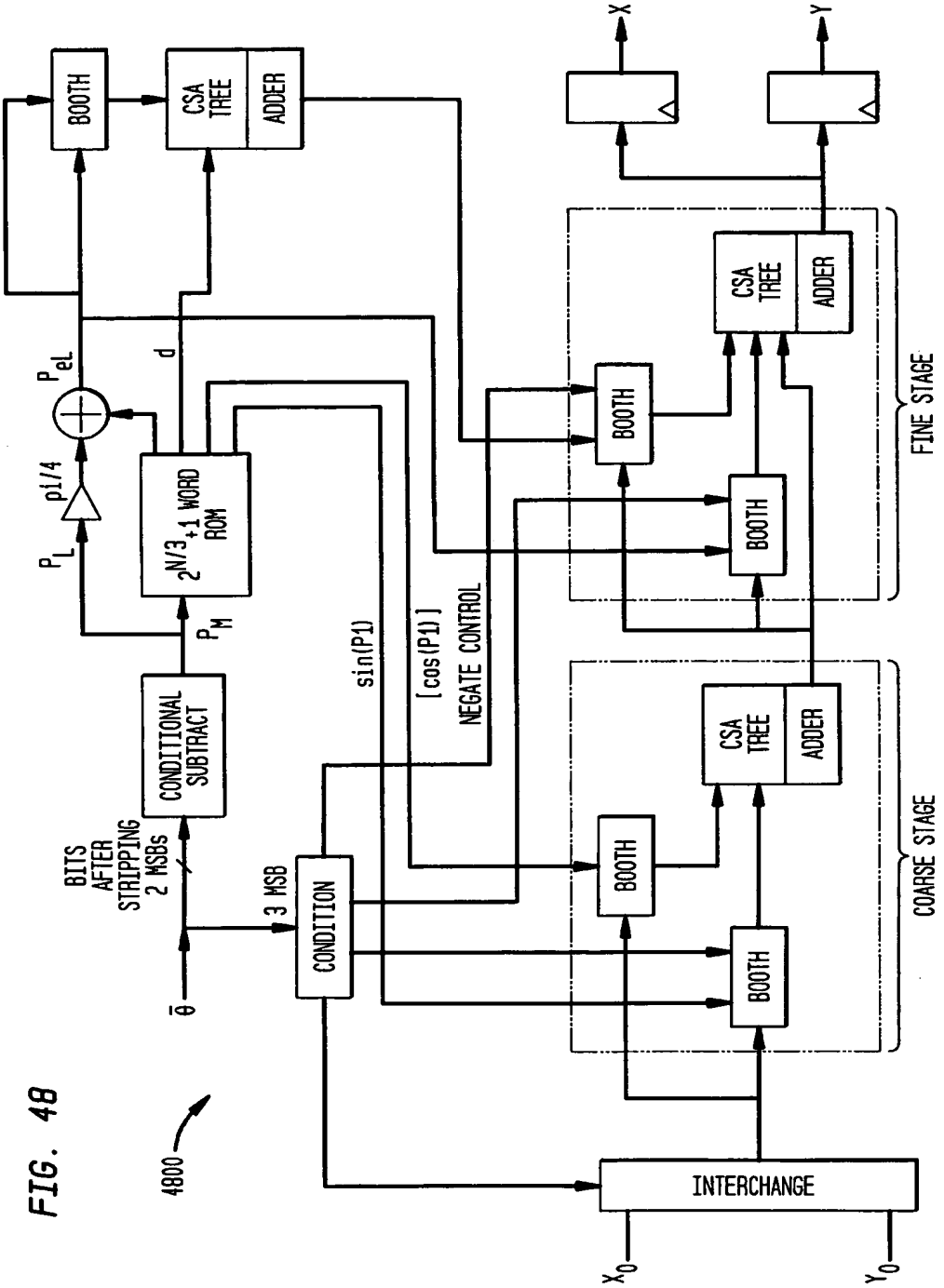
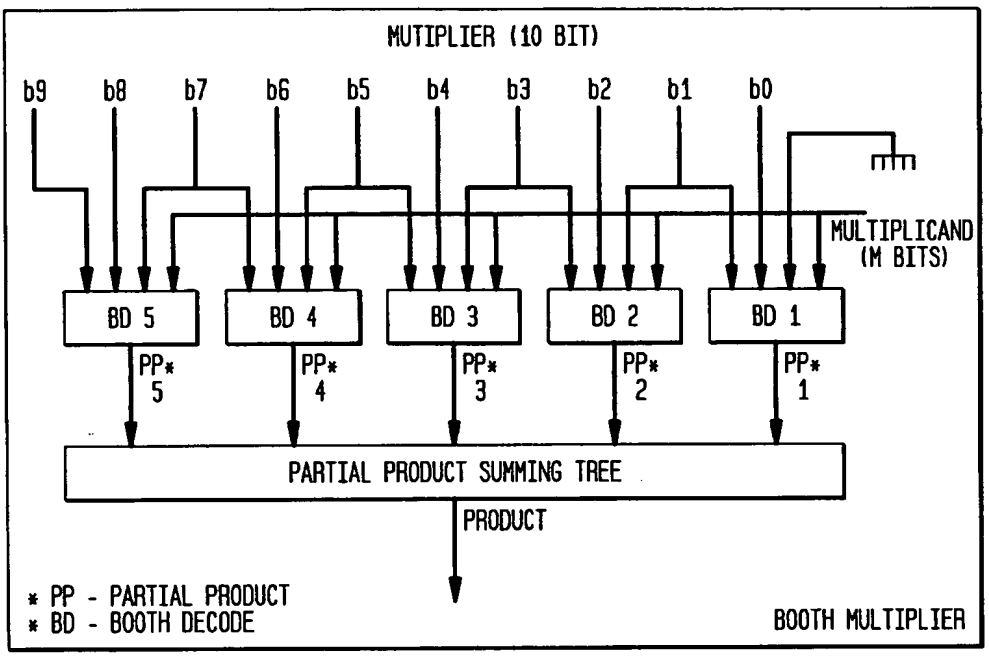
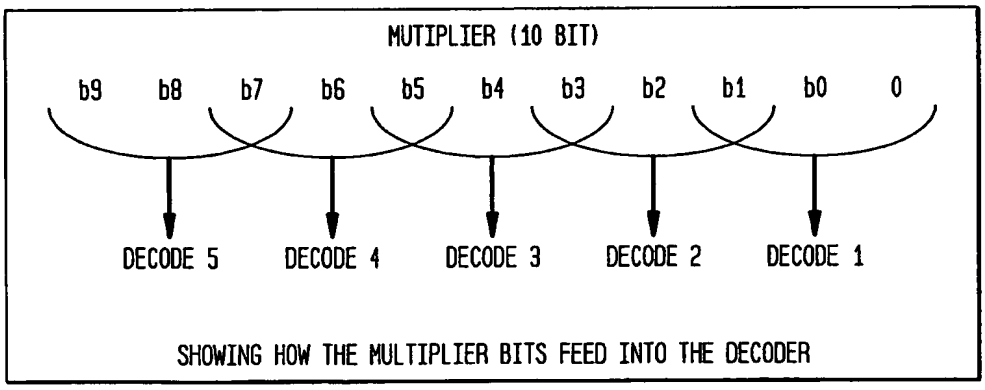

BOOTH
CSA TREE
ADDER
X
Y
$P_{eL}$
d
$P_L$
pi/4
$2^{N/3}+1$ WORD ROM
$P_M$
CONDITIONAL SUBTRACT
BITS AFTER STRIPPING 2 MSBs
$\theta$
3 MSB
CONDITION
sin(P1)
[cos(P1)]
NEGATE CONTROL
FINE STAGE
COARSE STAGE
INTERCHANGE
$X_0$
$Y_0$
4800

FIG. 48

FIG. 49


MUTIPLIER (10 BIT)
b9 b8 b7 b6 b5 b4 b3 b2 b1 b0
MULTIPLICAND (M BITS)
BD 5
BD 4
BD 3
BD 2
BD 1
PP* 5
PP* 4
PP* 3
PP* 2
PP* 1
PARTIAL PRODUCT SUMMING TREE
PRODUCT
* PP - PARTIAL PRODUCT
* BD - BOOTH DECODE
BOOTH MULTIPLIER


MUTIPLIER (10 BIT)
b9 b8 b7 b6 b5 b4 b3 b2 b1 b0 0
DECODE 5
DECODE 4
DECODE 3
DECODE 2
DECODE 1
SHOWING HOW THE MULTIPLIER BITS FEED INTO THE DECODER

5000

FIG. 50

ORIGINAL BOOTH TABLE 5002

| b2 | b1 | b0 | PP |
|---|---|---|---|
| 0 | 0 | 0 | 0*A |
| 0 | 0 | 1 | 1*A |
| 0 | 1 | 0 | 1*A |
| 0 | 1 | 1 | 2*A |
| 1 | 0 | 0 | -2*A |
| 1 | 0 | 1 | -1*A |
| 1 | 1 | 0 | -1*A |
| 1 | 1 | 1 | 0*A |

5100

FIG. 51

NEGATING BOOTH TABLE 5102

| b2 | b1 | b0 | PP |
|---|---|---|---|
| 0 | 0 | 0 | 0*A |
| 0 | 0 | 1 | -1*A |
| 0 | 1 | 0 | -1*A |
| 0 | 1 | 1 | -2*A |
| 1 | 0 | 0 | 2*A |
| 1 | 0 | 1 | 1*A |
| 1 | 1 | 0 | 1*A |
| 1 | 1 | 1 | 0*A |

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For: Apparatus and Method for Rectangular-to-Polar Conversion



FIG. 52

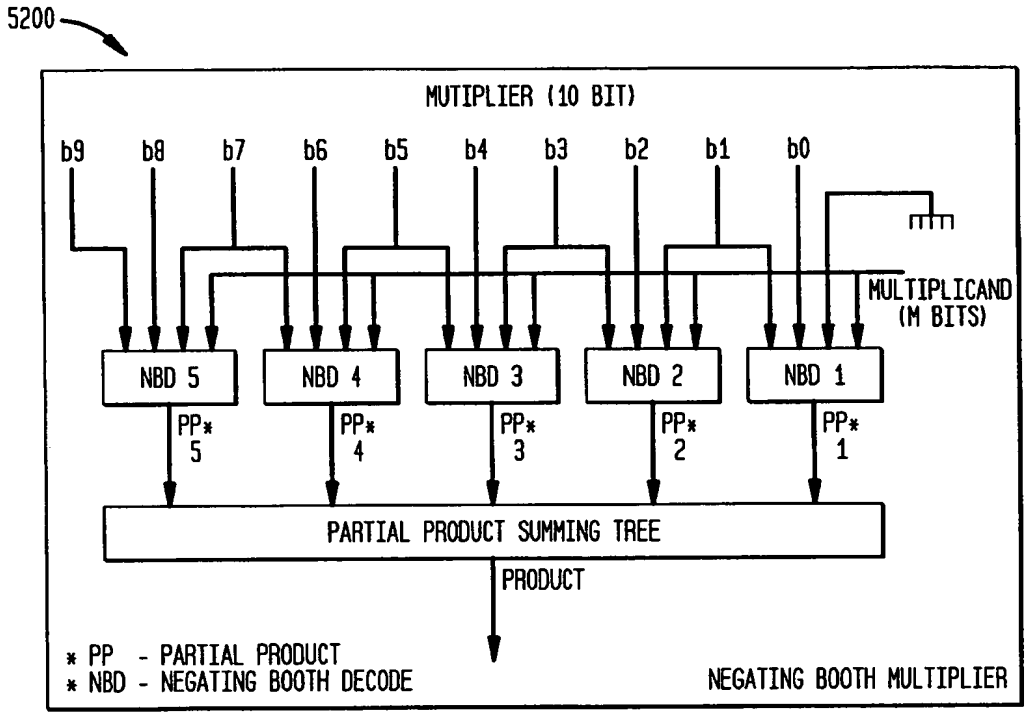

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FIG. 53

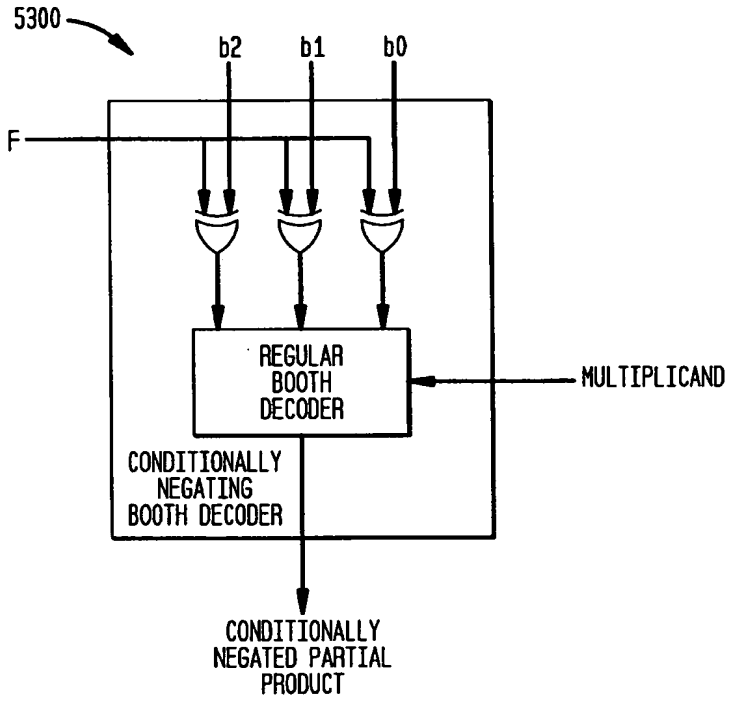
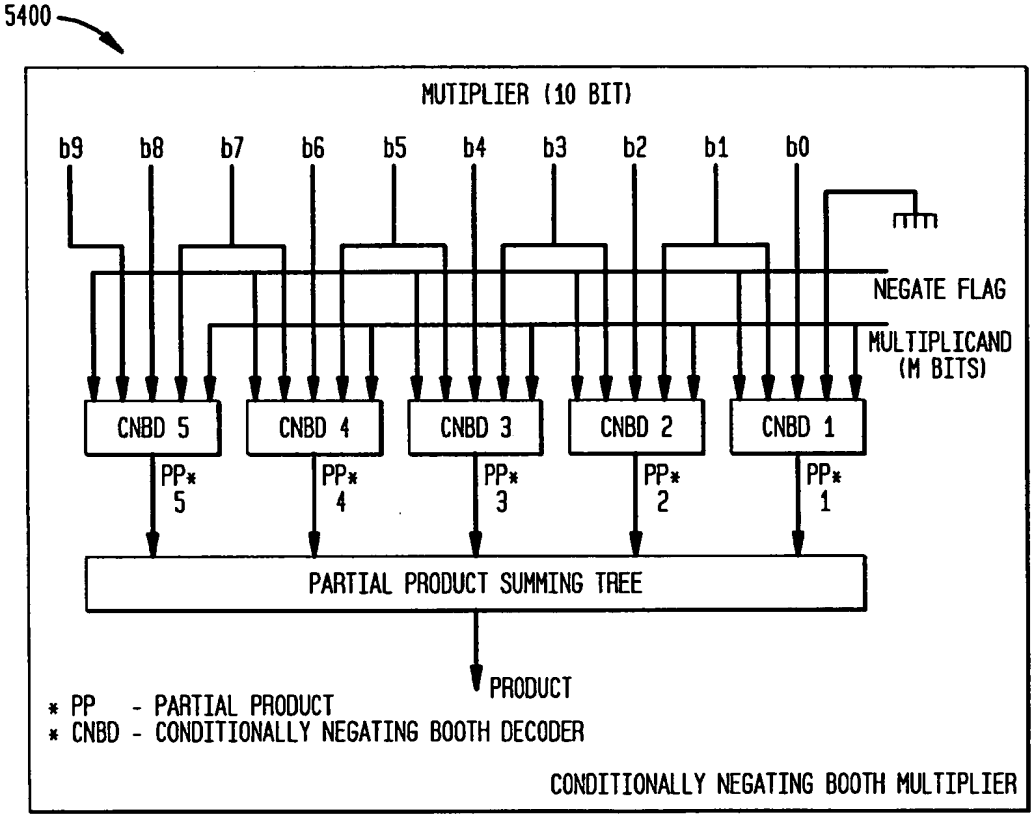


FIG. 54


5400
MUTIPLIER (10 BIT)
b9
b8
b7
b6
b5
b4
b3
b2
b1
b0
NEGATE FLAG
MULTIPLICAND (M BITS)
CNBD 5
CNBD 4
CNBD 3
CNBD 2
CNBD 1
PP* 5
PP* 4
PP* 3
PP* 2
PP* 1
PARTIAL PRODUCT SUMMING TREE
PRODUCT
* PP - PARTIAL PRODUCT
* CNBD - CONDITIONALLY NEGATING BOOTH DECODER
CONDITIONALLY NEGATING BOOTH MULTIPLIER

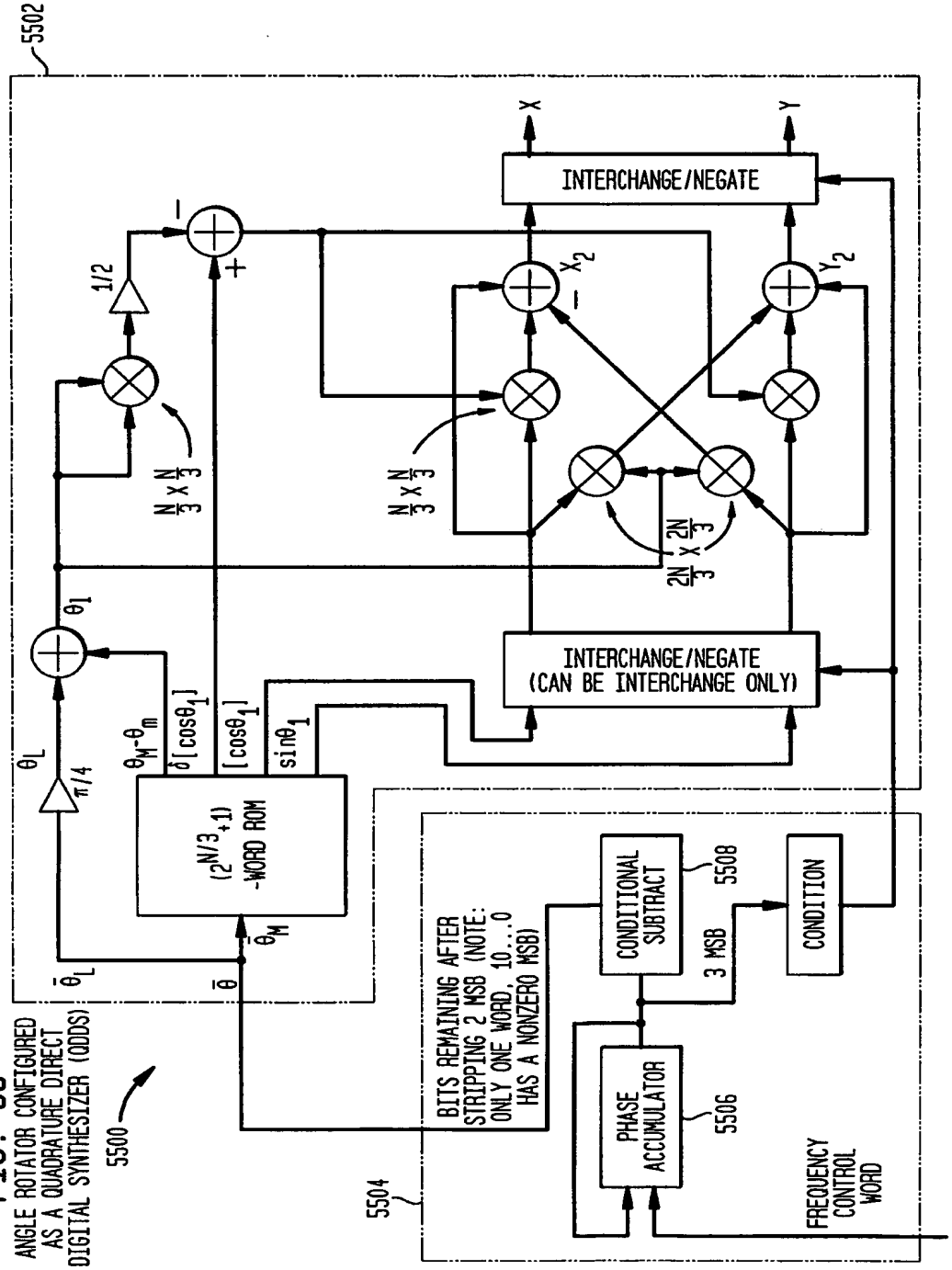



FIG. 55
ANGLE ROTATOR CONFIGURED AS A QUADRATURE DIRECT DIGITAL SYNTHESIZER (ODDS)

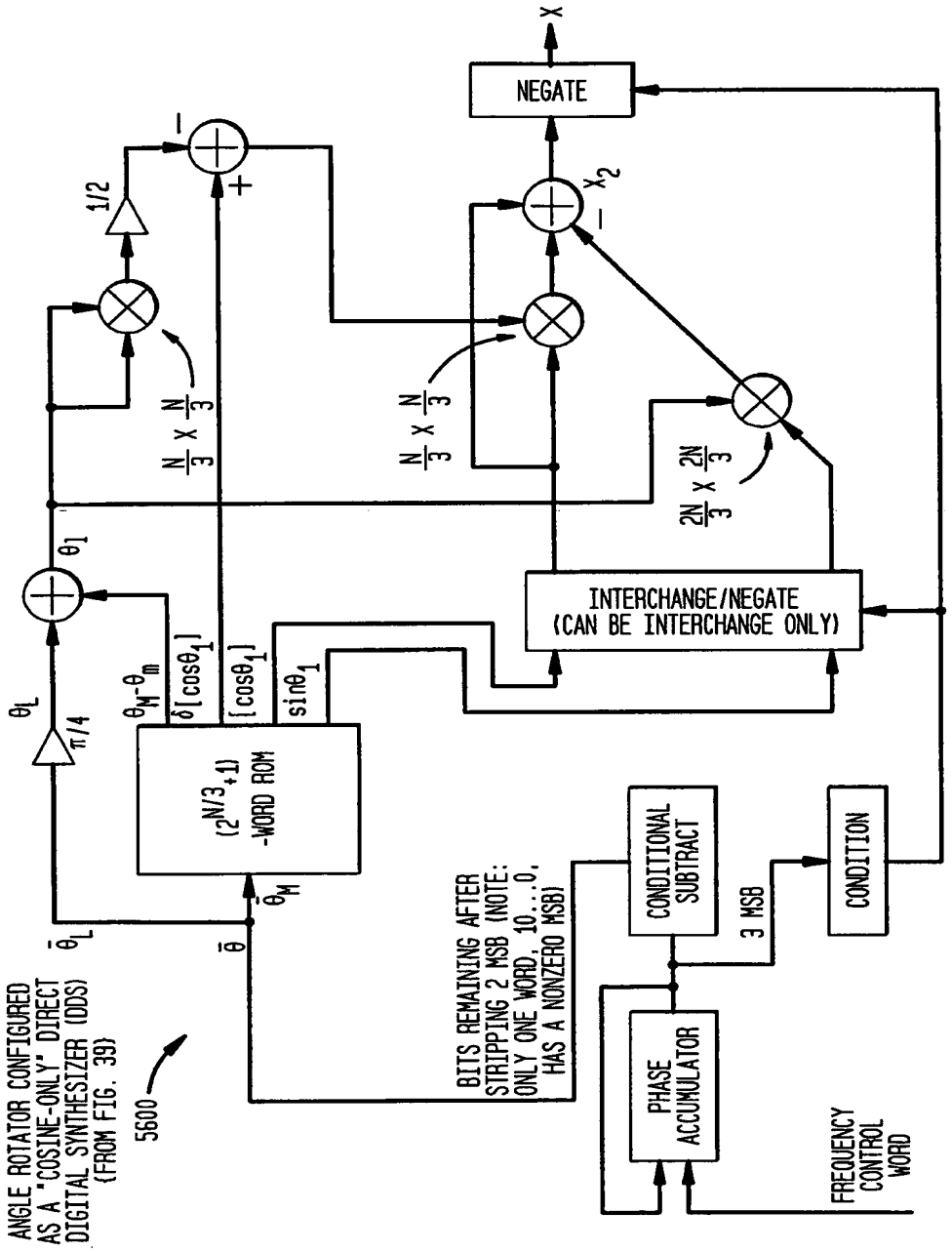



FIG. 56
ANGLE ROTATOR CONFIGURED AS A 'COSINE-ONLY' DIRECT DIGITAL SYNTHESIZER (DDS) (FROM FIG. 39)

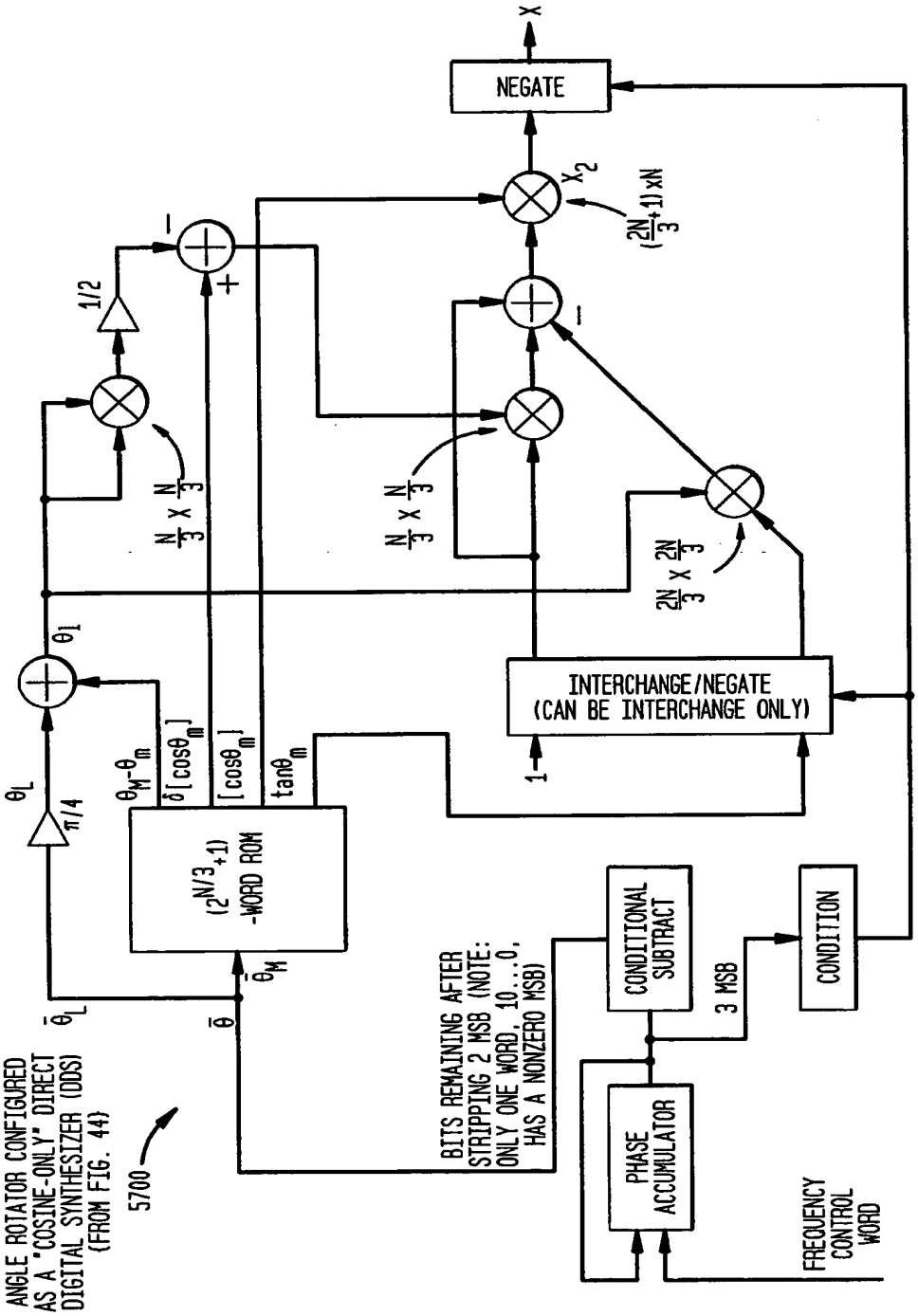



FIG. 57
ANGLE ROTATOR CONFIGURED AS A "COSINE-ONLY" DIRECT DIGITAL SYNTHESIZER (DDS) (FROM FIG. 44)

*FIG. 58*
COMMON PACKET FORMAT

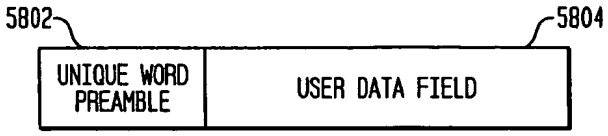



*FIG. 59*
THE SIMPLIFIED SYSTEM MODEL

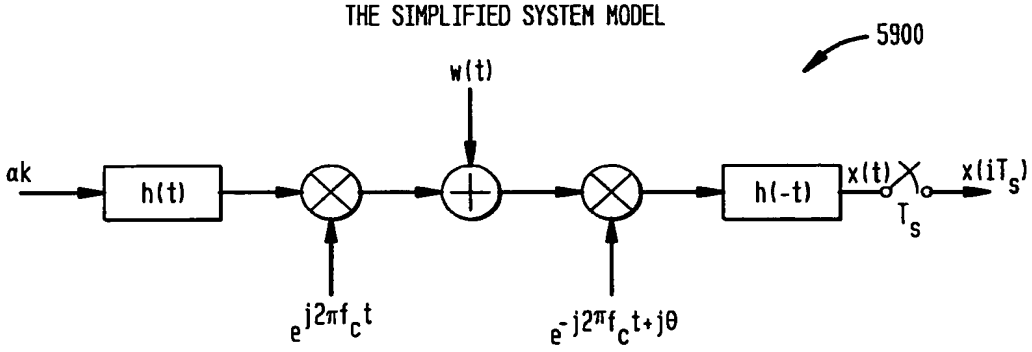
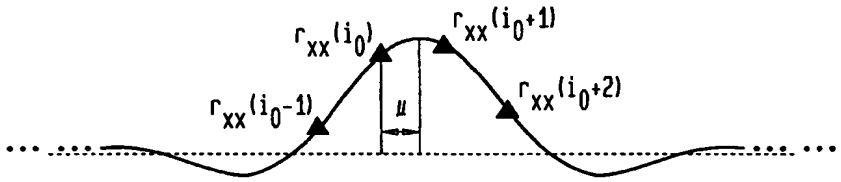



*FIG. 60*
MEAN VALUES OF THE PREAMBLE CORRELATOR OUTPUT, FOR θ=0



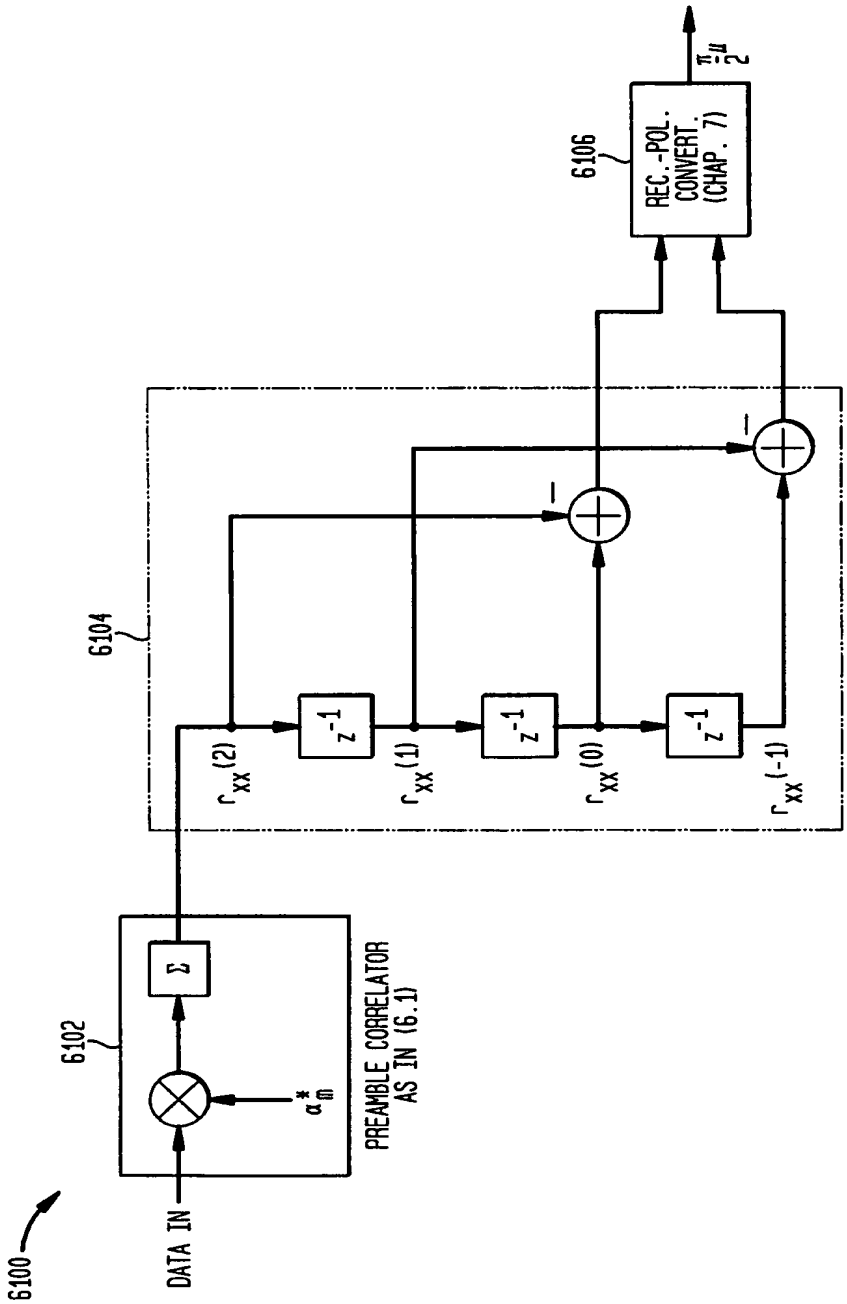



FIG. 61
PRELIMINARY SYMBOL-TIMING ESTIMATION STRUCTURE

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For: Apparatus and Method for Rectangular-to-Polar Conversion



FIG. 62

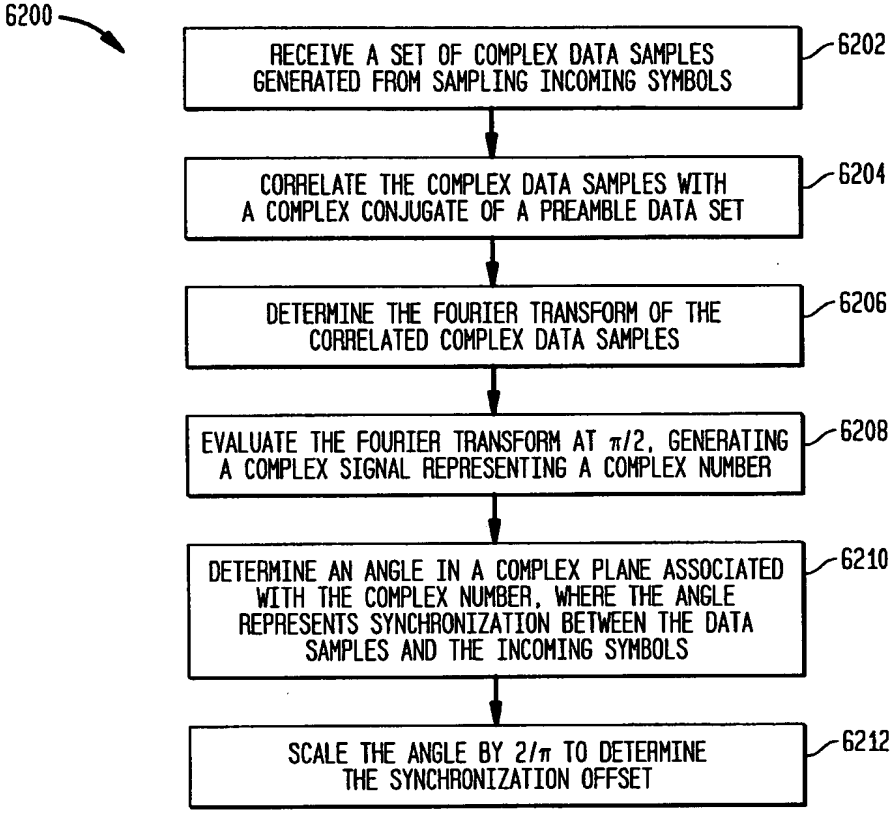
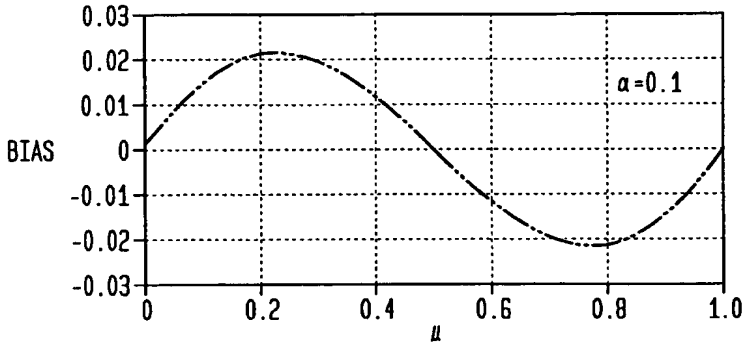



FIG. 63

BIAS DUE TO TRUNCATION



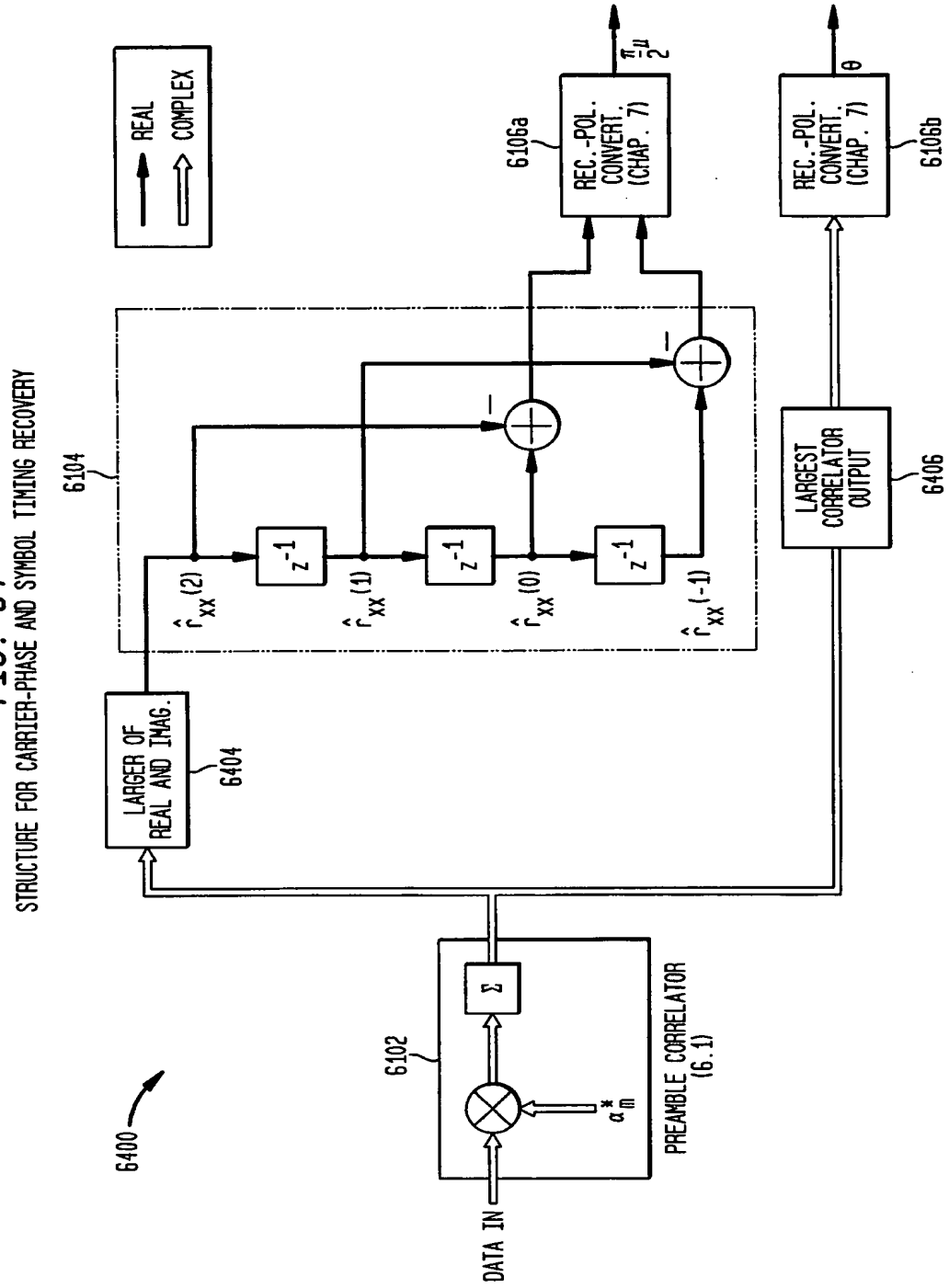



FIG. 64
STRUCTURE FOR CARRIER-PHASE AND SYMBOL TIMING RECOVERY

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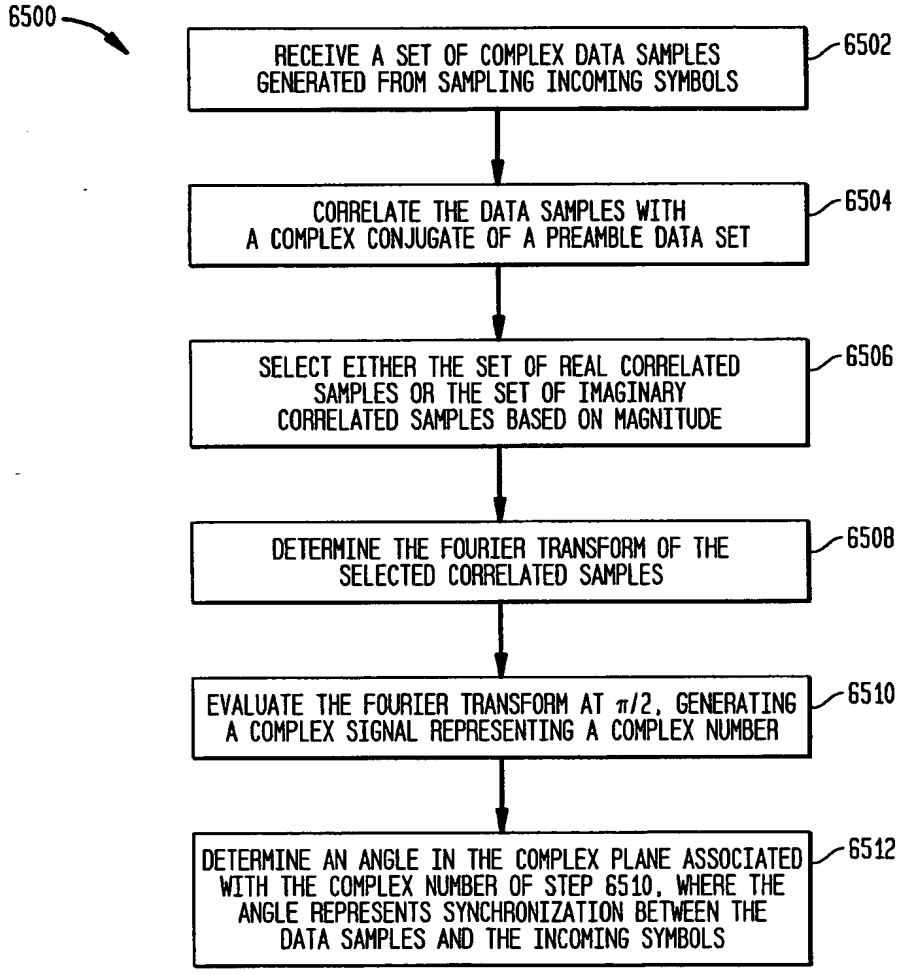
For: Apparatus and Method for Rectangular-to-Polar Conversion



FIG. 65A



6500 (CONT.)

FIG. 65B

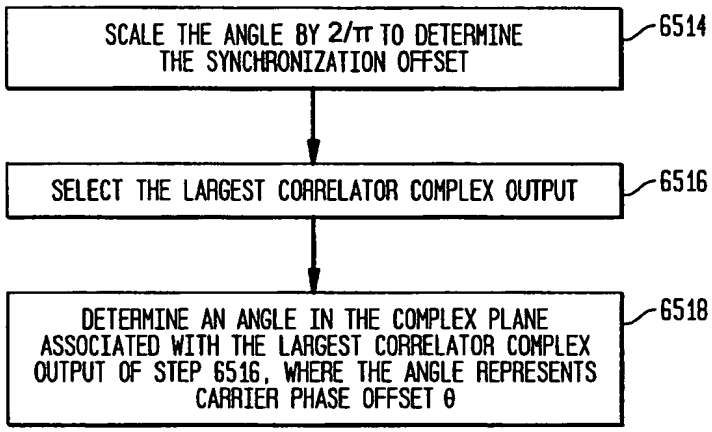


FIG. 66

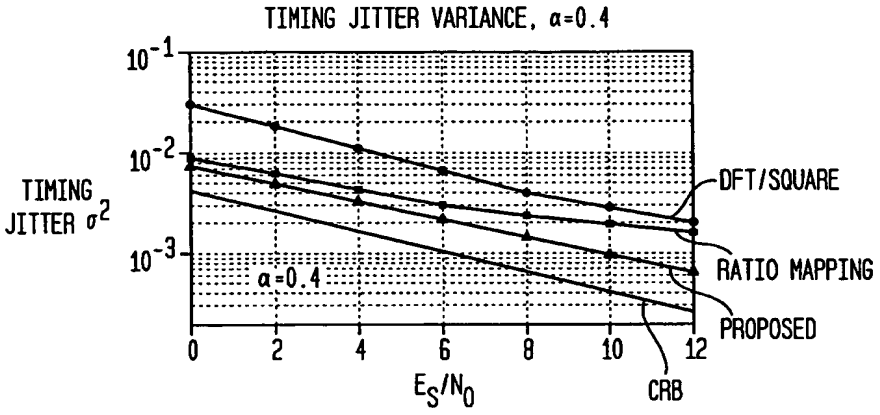



FIG. 67

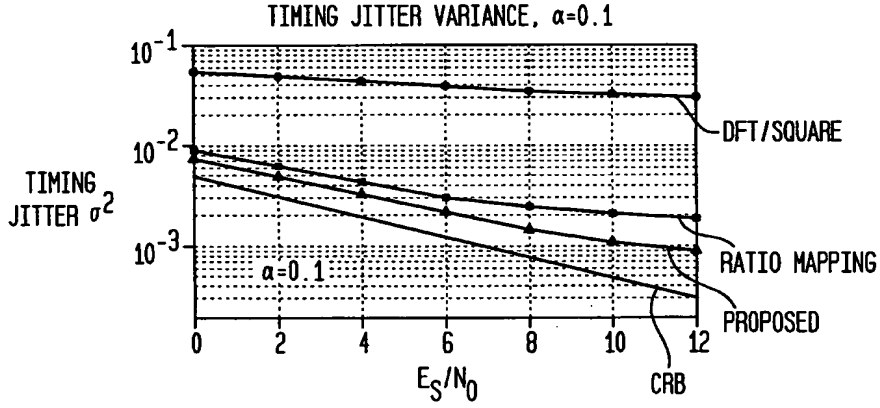



FIG. 68

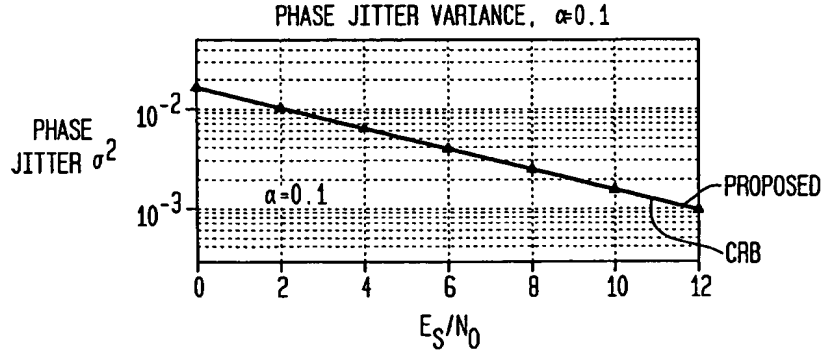


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FIG. 69
CARTESIAN TO POLAR CONVERSION

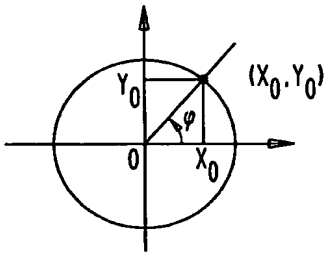


FIG. 70A
USING NEWTON-RAPHSON ITERATION TO FIND $1/X_1$

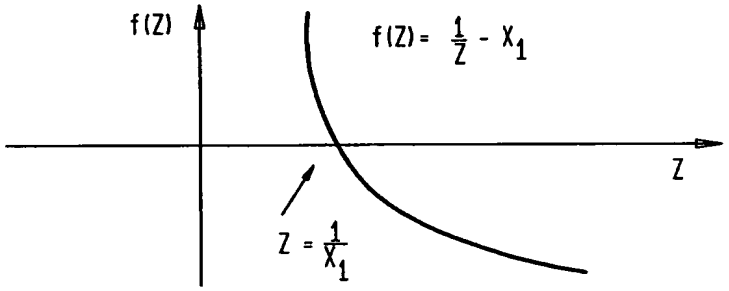


FIG. 70B
ONE NEWTON-RAPHSON ITERATION

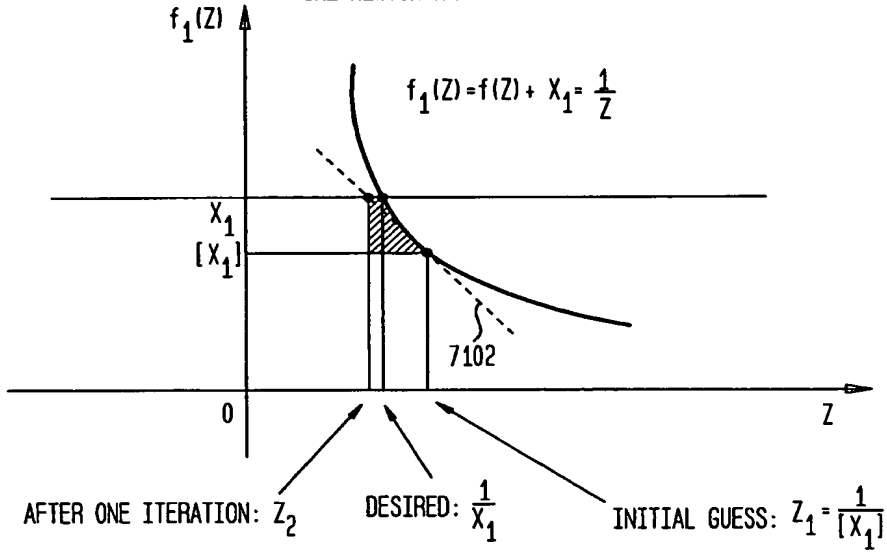

FIG. 71

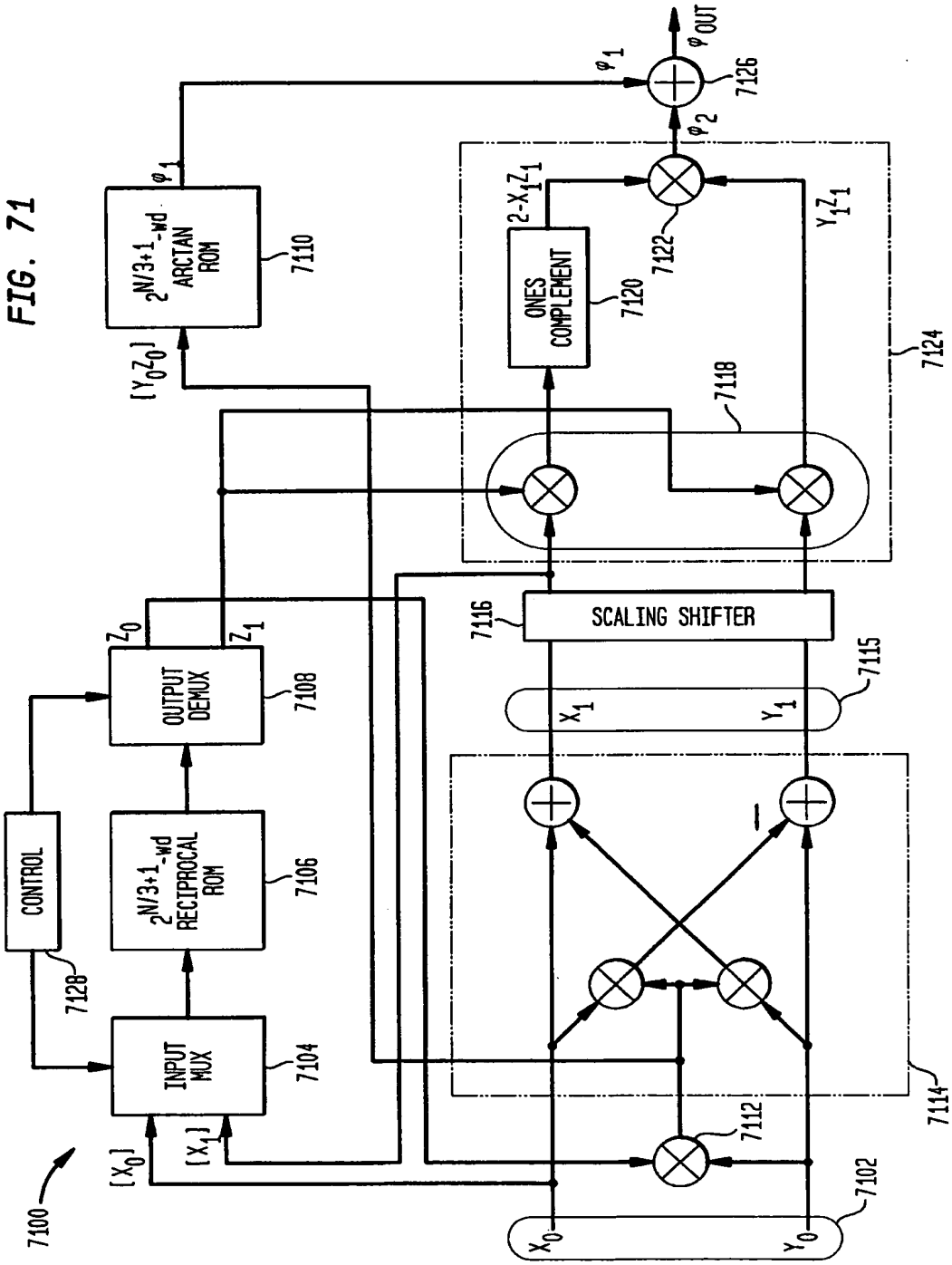
7100
CONTROL
7128
INPUT MUX
7104
$2^{N/3+1}$-wd RECIPROCAL ROM
7106
OUTPUT DEMUX
7108
$2^{N/3+1}$-wd ARCTAN ROM
7110
ONES COMPLEMENT
7120
7122
7124
7126
7112
7114
7115
7116
SCALING SHIFTER
7118
7102
$\varphi_1$
$\varphi_2$
$\varphi_{OUT}$
$[X_0]$
$[X_1]$
$[Y_0 Z_0]$
$Z_0$
$Z_1$
$X_0$
$Y_0$
$X_1$
$Y_1$
$2-X_1Z_1$
$Y_1Z_1$

FIG. 72

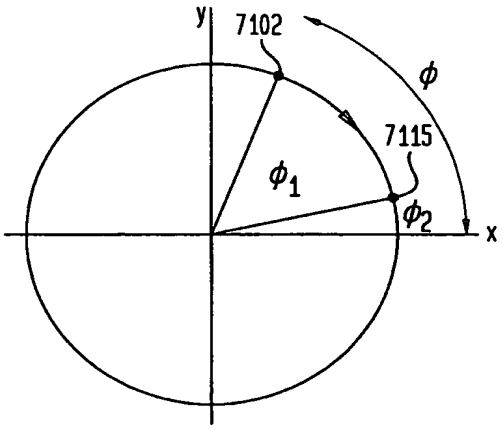


FIG. 74

INTERPOLATION IN A NON-CENTER INTERVAL

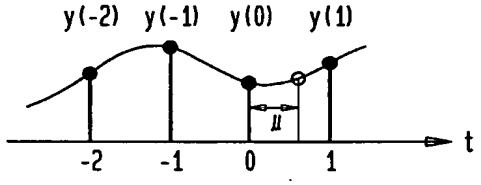

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FIG. 73

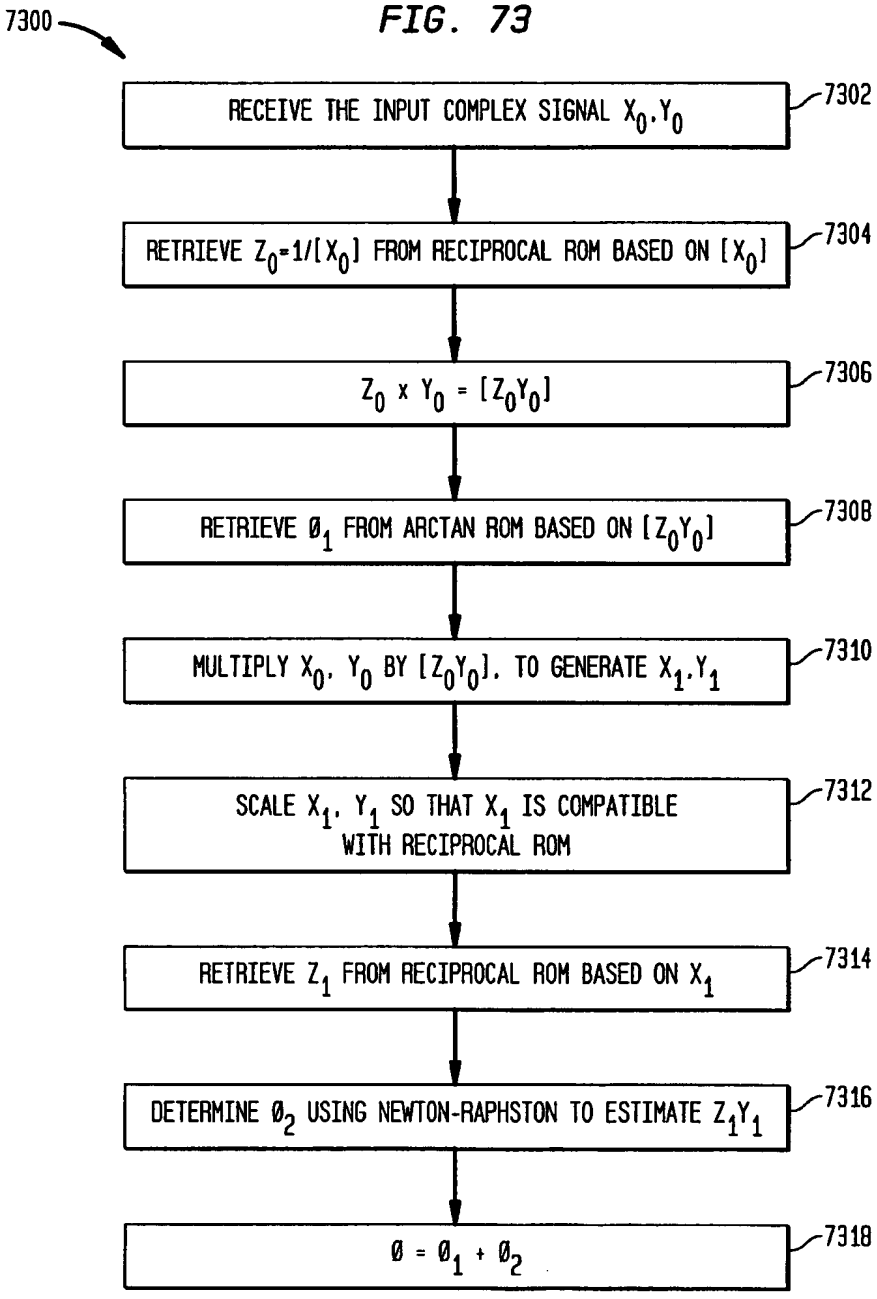

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*FIG. 75A*

IMPULSE RESPONSES OF THE NON-CENTER-INTERVAL INTERPOLATION FILTER BEFORE OPTIMIZATION

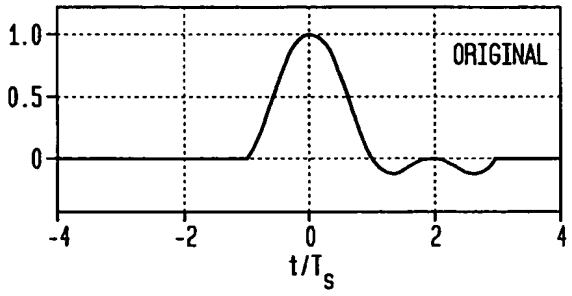


*FIG. 75B*

IMPULSE RESPONSES OF THE NON-CENTER-INTERVAL INTERPOLATION FILTER AFTER OPTIMIZATION

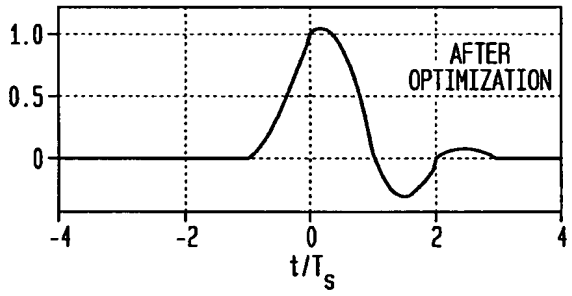

*FIG. 76A*

FREQUENCY RESPONSES OF THE NON-CENTER-INTERVAL INTERPOLATOR BEFORE OPTIMIZATION

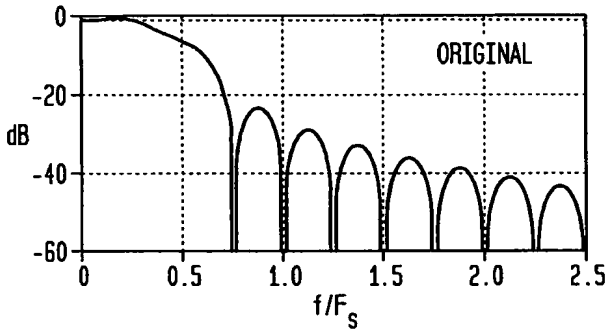


*FIG. 76B*

FREQUENCY RESPONSES OF THE NON-CENTER-INTERVAL INTERPOLATOR AFTER OPTIMIZATION

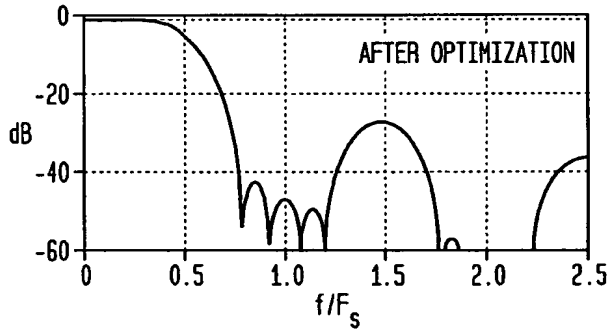

FIG. 77

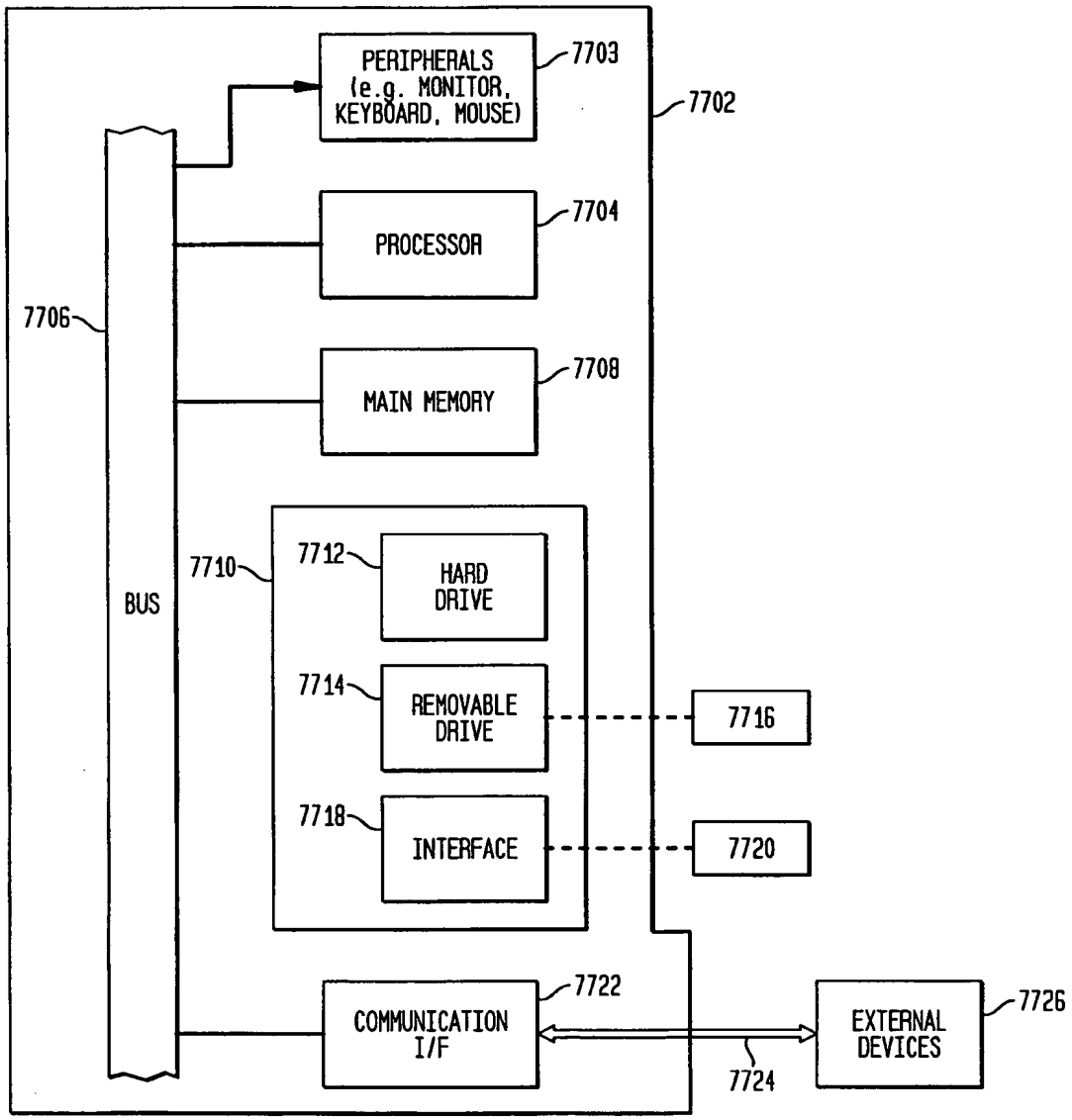
PERIPHERALS (e.g. MONITOR, KEYBOARD, MOUSE)
7703
7702
PROCESSOR
7704
7706
MAIN MEMORY
7708
BUS
7710
7712
HARD DRIVE
7714
REMOVABLE DRIVE
7716
7718
INTERFACE
7720
COMMUNICATION I/F
7722
EXTERNAL DEVICES
7726
7724

*FIG. 78*
DATA RATE EXPANSION CIRCUIT